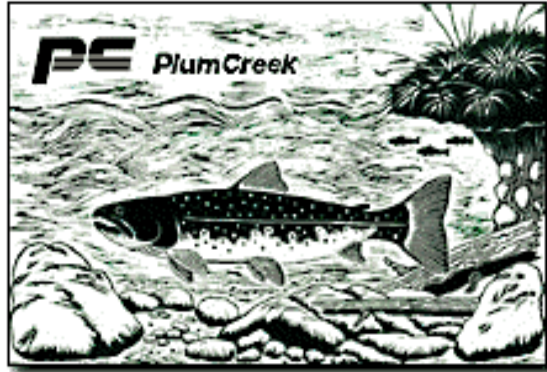# Adaptive Management: Concepts and Applications to Plum Creek's Native Fish Habitat Conservation Plan

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**Native Fish Habitat Conservation Plan
Technical Report No. 13**

Plum Creek Timber Company
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ABSTRACT

Plum Creek Timber Company is developing a Native Fish Habitat Conservation Plan (NFHCP) for bull trout and other native salmonids on nearly 1.7 million acres of corporate forestlands in Montana, Idaho, and Washington. An important component of the conservation strategy is adaptive management: a challenging blend of rigorous science and practical management designed to provide the basis for "learning by doing". Within the context of HCPs, adaptive management can be used to address significant technical "leaps of faith" when the permitting federal agencies and the applicant differ slightly in their view of what is needed but agree that it is important not to postpone conservation because of incomplete knowledge. The objectives of this technical report are two-fold: 1) to examine the concept and application of adaptive management; and, 2) propose research and monitoring projects that could advance the practice of adaptive management in Plum Creek's Native Fish Habitat Conservation Plan. Experimental designs for research and monitoring projects to support adaptive management can employ two different approaches. The first is a mensurative or "descriptive" approach, the results of which describe current or existing conditions. The second approach is a manipulative or experimental approach that seeks to test cause-effect relationships. For an adaptive management study to lead to plan modification, both the statistical significance and biological significance will be evaluated in assessing treatments and making management decisions. These triggers will be developed with the Services in the NFHCP. Research and monitoring projects identified for the NFHCP fall under 3 general categories that encompass a "certainty continuum" from highly confident to highly speculative subjects. These categories are 1) continuous improvement monitoring projects where results can be quickly integrated into operations; 2) experimental management projects where significant scientific uncertainty exists and therefore a more rigorous study design is required; and 3) basic research projects which represent highly speculative areas where underlying assumptions and cause-effect relationships require more investigation. A total of 15 potential projects covering major elements of the conservation strategy and supporting the NFHCP adaptive management program are described in detail. Final selection of the projects to be included and implemented in the NFHCP will involve consideration of recommended economic and technical criteria discussed in the report.

ACKNOWLEDGEMENTS

The contributors to this technical report go well beyond the authors listed on the title page. Mike Jostrom, Plum Creek's Native Fish HCP project leader, provided both insight and encouragement for us to complete this, the final of 13 technical reports, to support the scientific foundations of the HCP. Mic Holmes, Plum Creek's statistician, was instrumental in discussions of study design and statistical rigor.

We appreciate the advice from Dr. Kai Lee and the guidance that we absorbed from his book Compass and Gyroscope, as well as conversations that I had with him during the preparation of this report. Several of the authors traveled to Vancouver to visit with Dr. Carl Walters. Our time with Dr. Walters was valuable in providing a look at both the theoretical and practical side of adaptive management.

Ted Koch, with the U.S. Fish and Wildlife Service in Boise, Idaho reviewed earlier drafts of the report and offered constructive suggestions on both organization and application of the concepts discussed in this report. We appreciate the contributions and conversations of Bill Vogel with the USFWS Habitat Conservation Program in Olympia Washington.

We thank the outside peer reviewers of this report for taking time out of their busy schedules to offer comments, suggestions and criticisms of the content in this report.

Finally, I would like to thank my co-authors, several of whom were busy finishing other technical reports when we started this project, for their time and temperament in putting this document together. I hope we can all watch the ideas and opportunities discussed here put into play on the ground.

Lorin Hicks

November 21, 1998

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1.0   INTRODUCTION

I have come to think of science and democracy as compass and gyroscope - navigational aids in the quest for sustainability. Science linked to human purpose is a compass: a way to gage directions when sailing beyond the maps. Democracy, with its contentious stability, is a gyroscope: a way to maintain our bearing through turbulent seas. Compass and gyroscope do not assure safe passage through rough, uncharted waters, but the prudent voyager uses all instruments available, profiting from their individual virtues.

> Kai N. Lee, Compass and Gyroscope

That which does not kill me only serves to make me stronger.

> Friedrich Nietzsche

There is only one thing more painful than learning from experience, and that is not learning from experience.

> Archibald MacLeish

Plum Creek Timber Company is developing a conservation strategy for bull trout (*Salvelinus confluentus)* and other native salmonids on nearly 1.7 million acres of corporate forestlands in Montana, Idaho and Washington (see section 2.0 for details). An important component of the conservation strategy is adaptive management: a challenging blend of rigorous science and practical management designed to provide the basis for "learning by doing."   The objectives of this technical report are two-fold: 1) to examine the concept and application of adaptive management; and, 2) propose research and monitoring projects that could advance the practice of adaptive management in Plum Creek's Native Fish Habitat Conservation Plan. The array of research and monitoring projects described in this report represent the opinions of the authors in consultation with outside experts and interests. The final suite of projects to be included in the HCP will be the result of continuing discussions between Plum Creek, the U.S. Fish and Wildlife and National Marine Fisheries Services, the two federal agencies who must approve the HCP in its final form. It is likely that the final suite of projects will be a smaller subset of the projects described herein. The criteria for selection (discussed in a later section) will depend on a variety of technical, operational and economic factors

1.1 Definitions

Natural resource management in the United States has been a curious and often confusing blend of science and policy. Decision makers typically depend on science as a foundation for defining and managing natural systems. However, human understanding of natural systems is incomplete and our effect on these systems can be viewed as "experiments". Adaptive management applies the concept of experimentation to design and implementation of natural resource plans and policies (Lee 1993). Adaptive management begins with the central tenet that management involves a continual learning process that cannot be conveniently assigned as "research" and "regulatory compliance" activities (Walters 1986). Adaptive management is highly advantageous when policy-makers and managers face uncertainty; when the question becomes "how can you know that something will work until you try it?" The adaptive approach is needed if scientific uncertainty is to expedite socially timely action (Lee 1993). As stated by Jensen et al. (1996), adaptive management is not an excuse for shoddy management; instead it requires explicit hypotheses about system structure composition and function, a clear statement of management goals, defined management actions and anticipated ecosystem response.

1.2 Applications to Resource Management

Pioneering development in adaptive management began in Europe in the late 1960's as an interdisciplinary approach to "adaptive environmental assessment" for more effectively constructing and testing simulation models for natural resource management (Hollings 1978; Walters 1986). Although adaptive management has been most often applied to fisheries issues such as Pacific salmon management and stock recruitment rates under different ocean harvest strategies, the concept has recently been applied to an increasingly wider variety of resource management issues such as forest insect outbreaks, elk and waterfowl harvest regulations, riparian and coastal environments, and northwest forest ecosystems (Walters 1986; Walters 1997; Gratson et al. 1993; Nichols and Johnson 1989; Johnson et al. 1993; Kohm and Franklin 1997).

Adaptive management has been advocated as an approach to the Northwest Power Planning Council's fish and wildlife program in the Columbia River Basin. In this context, adaptive management was seen as an opportunity to incorporate experimentation at the landscape scale to address listed and unlisted fish and wildlife species as well as human communities (Volkman and Lee 1994). The Council's proposed direction regarding restoration of fish and wildlife resources in the Columbia Basin seeks to incorporate active experimentation to provide better understanding and development of new tools to assess abundance and condition of populations and biological processes (NWPPC 1998).

Adaptive management has been widely advocated as a means to directly compare

management options and help resolve basic uncertainties about the response of managed ecosystems to human disturbance. Walters and Green (1997) presented a review of 11 resource management situations where an adaptive management approach has been implemented or attempted. The authors presented an accounting framework based on expected net present value to compare design alternatives for cost and effectiveness. The use of a combination of biological and social/economic indicators is advocated by Lee (1998) to enable people to navigate through a "sustainability transition."

In discussing the need to better understand the influence of timber harvest on avian communities, Marzluff (1997) suggested that the rewards of embracing "uncertainty" and managing adaptively would be an increased likelihood of correctly predicting harvest prescription outcomes and flexibly balancing competing resource demands. He recommended maintenance of long-term research designed to uncover and understand mechanisms that relate timber harvest to avian population viability.

In the last decade, much work has been done to incorporate experimentation and adaptive management into forest management at the stand level (Hicks 1991; Zielke 1993, Franklin et al. 1997). In assessing the ecological and economic implications of three different silvicultural prescriptions for riparian restoration in the western Cascades, Berg (1995) concluded that introduced improvements (active management of the forest) can be more effective in restoring the riparian system than no intervention at all, because of the added time for natural processes to develop and the added economic incentives of intermediate timber revenues. He observed that adaptive management can be summarized as planning (system design), monitoring, evaluation, and adjustment (Berg 1995).

Adaptive management figured highly in the report of the Forest Ecosystem Management Assessment Team (FEMAT 1993) and became an integral part of the President's Northwest Forest Plan finalized in 1994. Nearly 2 million acres in 10 areas of Washington, Oregon and northern California were designated as Adaptive Management Areas where the primary objective is to "learn how to do ecosystem management in terms of both technical and social challenges, and in a manner consistent with applicable laws". The FEMAT group defined adaptive management as "the process of implementing policy decisions as scientifically driven management experiments that test predictions and assumptions in management plans, and use the resulting information to improve the plans." With the dual emergence of both ecosystem management and adaptive management, forestry has been transformed from an isolated technical activity to an exercise in "civic science": interdisciplinary, multi-jurisdictional and hierarchical in complexity (Kohm and Franklin 1997; Lee 1993). An understanding and successful implementation of these concepts is necessary if forestry is to embrace the ambiguity of multiple objectives, the uncertainty of diverse perspectives, and the possibility of

surprise outcomes.

Monitoring to support decision-making at both the project and policy level is advocated by the Montana Bull Trout Restoration Team (Sanborn et al. 1998). A strategy proposed to the Restoration Team includes monitoring to establish baseline conditions and effectiveness of proposed actions, criteria based standards for assuring adequate levels of major habitat components, and caution zones where land management activities have the greatest potential to adversely affect bull trout habitat. Sanborn et al. (1998) recommend interagency and interdisciplinary coordination to develop monitoring methodologies, design monitoring programs, review monitoring efforts and maintain consistency as a mechanism to facilitate adaptive management.

The Timber-Fish-Wildlife Program in Washington has begun development of an Effectiveness Monitoring and Evaluation Program Plan (Schuett-Hames 1998), which contains five major components (**Figure 1**):

- Site-scale practice evaluation
- Watershed-scale management system
- Aquatic resource trends assessment
- CMER / MSC effectiveness information bank
- Adaptive management process

The goal of the TFW adaptive management process is to develop recommendations to improve the performance of forest practices, restoration measures and management systems (e.g., forest practices rules, watershed analysis, HCPs, landscape plans) using information generated by the TFW Effectiveness Monitoring and Evaluation Program. As situations are identified where aquatic resource objectives are not being met, the Cooperative Monitoring Evaluation Research / Monitoring Steering Committees (CMER / MSC) will convene adaptive management committees composed of individuals with relevant scientific and operational expertise to evaluate the information and make recommendations. The type of recommendation can include:

1) the range of site conditions where it is appropriate to apply the forest practice, restoration measure or management system;
2) refinements to improve performance in difficult situations;
3) alternatives for difficult situations;
4) focused research when existing information is insufficient to draw conclusions or identify solutions.

Site-Scale Practice Evaluation Component	Watershed-Scale Management System Evaluation Component	Aquatic Resource Trend Assessment Component
Site-scale evaluation of the effects of various practices on cause-effect pathways relevant to aquatic resources, including: • Timber management practices • Riparian management practices • Road management practices • Restoration practices	Watershed-scale evaluation of the effects of multiple practices on eight cause-effect pathways by management system type • Watershed Analysis • HCPs • Standard Forest Practice Rules • Landscape Plans	Regional-scale assessment of trends in aquatic resource conditions: • Salmonid habitat and populations • Other aquatic organisms • Water quality • Water quantity

CMER/MSC Effectiveness Information Bank Component
- Clearinghouse for information from the CMER/MSC, TFW participants, others
- Contains data and analyzed results organized by situational categories
- Easy access to information needed by TFW participants

Adaptive Management Process Component
- Adaptive Management Committee reviews results
- Provides recommendations for appropriate application of practices, refinement of practices, and alternative practices

Management System Effectiveness Report	Practice Effectiveness Report	Aquatic Resource Trend Assessment Report

Figure 1. The Timber-Fish-Wildlife Program in Washington has begun development of an Effectiveness Monitoring and Evaluation Program Plan (Schuett-Hames 1998).

The Upper Columbia River Basin Planning Team defined adaptive management as a "continuing process of planning, implementation, monitoring, and evaluation to adjust management strategies to meet goals and objectives of ecosystem management"(USDA Forest Service and USDI Bureau of Land Management 1997). They identified four types of monitoring (Figure 2) needed to meet management objectives and to evaluate management practices:

- **Implementation monitoring** -to determine if standards and guidelines are being properly implemented (also known as *compliance monitoring*).
- **Effectiveness monitoring**-to determine if the implementation of practices has achieved the desired objective. Success may be measured against the benchmark of "desired future conditions".
- **Validation monitoring**-to determine if cause-effect relationships exist among management practices and resources being addressed in the plan. Validation monitoring involves the confirmation of whether the predicted results occurred and if assumptions and models used in developing the plan are correct. This type of monitoring can be the most expensive but the most essential type of monitoring for adaptive management.
- **Baseline monitoring**-to establish reference conditions by monitoring elements or processes that may be affected by management practices. The reference conditions are generally natural and relatively unaffected by human activities.
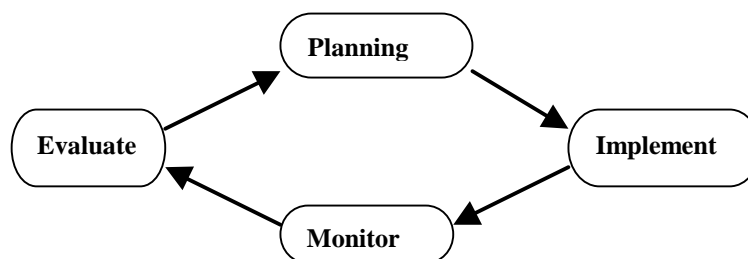
Figure 2. Adaptive management process (after USFS and BLM 1997).

Plum Creek initiated three pilot landscape management projects in 1995 in an effort to develop and assess the potential for application of an ecosystem-based approach to commercial forest management in the Northern Rockies. The landscape-scale assessments of current and potential future conditions of fish, wildlife, and watershed resources are seen within Plum Creek as a logical next step forward from stand-level experiments in alternative silviculture begun in 1990 (Hicks 1991). The pilot landscape management project areas have been instrumental in developing the information and analyses used in the NFHCP and will be useful in providing opportunities for adaptive

management experiments. The three pilot project areas include the Swan River Basin (408,630 acres total area; 82,718 acres Plum Creek ownership), located southeast of Kalispell, Montana; the Thompson River Basin (410,095 acres total area; 169,476 acres Plum Creek) located west of Kalispell, Montana; and the Harvey/ LeClerc Project Area (98,242 acres total area; 18,856 acres Plum Creek) in the Pend Oreille Valley of northeast Washington state. These areas were selected to represent a range of ecological conditions within the Northern Rockies, while addressing a diversity of resource utilization issues and varying spatial relationships between Plum Creek and other lands. The Harvey / LeClerc Project Area was discontinued in 1996 after sale of Plum Creek lands in the area to Stimson Timber Co. A key objective of the pilot landscape management areas will be to compare and expand management approaches for specific resource management issues such as native fish habitat to emerging issues such as habitat concerns for lynx and other forest carnivores. Application of an adaptive management philosophy will be instrumental in achieving this objective.

1.3 Adaptive Management and HCPs
Within the context of Habitat Conservation Planning, adaptive management is viewed as an agreement between the permitting agencies (U.S. Fish and Wildlife Service and National Marine Fisheries Service) and the applicant whereby the applicant's contribution to the conservation of the species or habitats will be modified in response to new information (Vogel 1998). Adaptive management can be used to address significant "leaps of faith" in HCPs where there is dependence on models and adoption of untested conservation measures. However, there is "dynamic tension" between the implementation of adaptive management in HCPs and adherence to the "No Surprises" policy that limits the amount of additional mitigation (e.g., acres, expenses, etc) that can be required of an applicant, unless unforeseen circumstances occur. Adaptive management provides the flexibility to deal with uncertainty within the sideboards of the recently revised "no surprises" policy.

Adaptive management is not simply a repository for unresolved issues. Adaptive management should be used to address areas of scientific uncertainty. For example, the Services are concerned about the effects of microclimate changes (e.g., canopy reduction in riparian areas from forestry) on stream temperatures. There are few data to support this relationship in the NFHCP planning area. Therefore, this could be a candidate topic for adaptive management. Habitat Conservation Planning is effective when a landowner is motivated to offer meaningful conservation through management prescriptions in order to receive greater certainty for management over the long term.   However, when incomplete science creates uncertainty, assurances through simple prescriptions may be inadequate. While the permitting agencies need the confidence that improved science will be taken into consideration into the future, the landowner needs to be confident that

conservation dollars expended will be cost effective and will benefit the resource. Since it is in both parties' interest not to postpone conservation to pursue more complete science, adaptive management becomes the tool to begin implementing conservation measures and improving certainty while science becomes more complete

Vogel (1998) identified some desirable components of an HCP adaptive management strategy, from a "permitting agency" perspective:

- Base strategy: a set of measures and prescriptions that are sufficiently robust so that the Services have a fair amount of confidence that they will be successful.
- Feedback: clearly defined levels that will trigger changes to the base strategy, linked to monitoring variables.
- Implementation: assurances to the Services that conservation measures will increase if needed. These assurances can be received if an applicant (1) waives the assurances policy with regard to the adaptive component of the HCP or (2) defines mitigation as achieving the objective rather than merely carrying out the prescription. The latter scenario is preferred by the Services.
- Limits to adjustment: it is acceptable for the Services to compromise with an applicant so that the investments made for conservation can be limited, establishing an upper limit beyond which the assurances policy would apply and applicant would not be required to provide additional mitigation, absent unforeseen circumstances.
- Adjustment increments: where possible, develop a mechanism whereby incremental adjustments can be made to a strategy (e.g., riparian management), based on monitoring information and continued testing. The timing of the change and how the parties work together to notify one another are important considerations. It is important to have these processes worked out in advance so the agencies and applicant can respond quickly when action is necessary.
- External factors: it is possible for the Services to commit to the need for differentiating between cause and effect, but they must ensure that they will be able to differentiate external factors (e.g., land management actions by others). Where possible, experimental design for adaptive management projects should be robust enough to differentiate treatment effects related to management strategies from external effects independent of land management actions. For example many factors may affect fish densities in streams (e.g., angling pressure) independent of habitat-related components such as large woody debris loading in streams.
- Direction of change: as a result of adaptive management, some conservation measures may become either more conservative (e.g., setting aside more habitat) or more aggressive (e.g., actively managing more habitat) compared to actions originally agreed upon with the Services. If the change desired is to become more conservative, the Services should document that change in cooperation with the

applicant. However, if the change would be to become more aggressive in management, the Services should perform an assessment of other impacts that may result, particularly when dealing with multiple species. If the amount of "take" were to increase, then a permit amendment might likely be necessary. Similarly, for a landowner to be motivated to offer meaningful adaptive management projects under an HCP, there has to be a high level of confidence that changes in protection levels can go either way under the guidance of better science. Incentive is preserved when acceptable levels of change are predetermined and well-defined contingencies and sideboards to the extent of changes are developed. This is a particular concern, which must be addressed in the design of monitoring programs to allow some inference into which factors are influencing response variables.

The Services recently proposed changes to their HCP Handbook to provide additional guidance in the five areas of monitoring, adaptive management, measurable biological goals, permit duration and public participation. These proposed changes are collectively referred to as the "5-points policy" (USFWS and NMFS 1998). The proposed handbook changes commit the Services to expanded use of adaptive management for all HCPs that cover situations for which significant biological data gaps exist, including the life history of the species as well as the probable effectiveness of proposed conservation measures.

1.4 Caveats of Adaptive Management

Despite the strong advantages and attractiveness of adaptive management as a practice and philosophy, some factors have limited the application of adaptive management. Ecosystem-level experiments may be impractical, infeasible, or pose equity questions (Northwest Power Planning Council 1998). Frissell[3] and Frissell and Bayles (1996) offered thoughts about why adaptive management cannot protect habitat of aquatic species, including the lag times for biological responses to disturbance, the difficulty in separating natural events from anthropogenic influences, and the differential response and sensitivity of aquatic ecosystems to human disturbance due to varying site conditions.

Walters (1997) identified four reasons for low success rates in implementing adaptive management policies in aquatic and coastal ecosystems. The first is a dependence on models and model development at the expense of adequate field experimentation. The second is a presumption that effective adaptive management experiments are excessively expensive or ecologically risky, compared to baseline options. Third, is strong

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3 Personal communication. <u>Ecosystem concepts in large-scale restoration</u>. Presentation to Montana Chapter, American Fisheries Society, 1998

opposition to experimental policies by people protecting various self-interests in bureaucracies, which provides opportunities to delay difficult decisions. Fourth, deep value conflicts within ecological and environmental interests create dissention about what are the desired future conditions in ecosystems where historical development has created "new" ecological values (such as the presence of "desirable" non-native fish species). As opined by Walters (1997), "the critical need today is not better ammunition for rational debate, but creative thinking about how to make management experimentation an irresistible opportunity, rather than a threat to various established interests. That is, we need to show that adaptive management can create win-win outcomes for scientists, bureaucratic administrators, politicians, and resource/environmental interest groups".

Models used at the outset of HCP's are appropriate "hypotheses" to describe relationships until field experience can provide more tangible knowledge. Adaptive management can provide a way to reduce reliance on models. However, some relationships such as large woody debris recruitment in streams experience considerable "lag effects" due to depletion from early practices and the length of time to grow more candidate trees next to streams. Consequently, the transition from models to field verification may vary considerably between issues and locations.

2.0 Description of Plum Creek Native Fish HCP

Plum Creek Timber Company's Native Fish HCP (NFHCP) is a 30-year plan to address the biological needs of bull trout and other salmonid fish species on the company's timberlands in Montana, Idaho, and portions of Washington. The purpose is to help conserve a broad range of aquatic species and the ecosystem upon which they depend while providing Plum Creek with long-term regulatory predictability and flexibility. Goals of the HCP are to:

- Provide habitat conditions in the planning area to help conserve and enhance aquatic species. Minimize and mitigate the impacts of commercial forest management activities on such species and their habitat.

- To the extent that unlisted species are covered by the Plan, put in place a set of conservation measures that would help eliminate the need to list such species in the future.

- Provide Plum Creek with predictability and flexibility to manage its timberlands economically into the future under "no surprises" assurances given by the Services.

The HCP is actually a impact minimization and mitigation plan that identifies and

assesses the potential for Plum Creek's forest management operations to impact ESA-listed salmonid species now and in the future. The HCP then displays the technical basis for a series of conservation measures to minimize and mitigate the impact ("take") on aquatic species to the maximum extent practicable. Finally, the HCP establishes a research and monitoring program to incorporate new information and evaluate the effectiveness of the plan.

The HCP is being developed with assistance of the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, the two federal agencies with statutory responsibilities to approve the HCP under the Endangered Species Act. Once completed and approved, the Services will issue Plum Creek an "incidental take permit", which authorizes the company to conduct its forest management activities within the habitat of listed species in concurrence with the HCP.

2.1 Project Area

The project area covers approximately 1.7 million acres of Plum Creek lands in the Northwest, as follows:

1,462,000 acres	Montana
134,000 acres	Idaho
85,000 acres	Washington
1,681,000 acres	**Total project area**

Figures 3 and 4 are maps showing the distribution of Plum Creek lands in the three-state project area. Plum Creek lands in the NFHCP project area comprise a significant percentage of the Flathead, Kootenai, Thompson, Swan, and Blackfoot River drainages in Montana. The NFHCP project area also includes Plum Creek ownership in the Lochsa, Little North Fork Clearwater, and St. Joe River basins in Idaho and the Tieton, Ahtanum, and Lewis River basins in Washington. Much of the company lands in the project area are in a "checkerboard" pattern with state, federal, and other private landowners. For more information on the management practices and policies governing other lands in the project area and the distribution of Plum Creek ownership by basin, see Sugden and Light (1998).

Based on surveys completed by Plum Creek and data obtained by state agencies and the Services, watersheds and streams in the project area have been designated as follows for the purpose of designing appropriate conservation measures:

Tier 1 Watersheds contain streams known to be important for bull trout spawning and juvenile rearing. This part of the life cycle of bull trout is particularly sensitive and has the most specific habitat needs. About 20% of the PCTC land in the NFHCP project area occur within 81 Tier 1 watersheds.
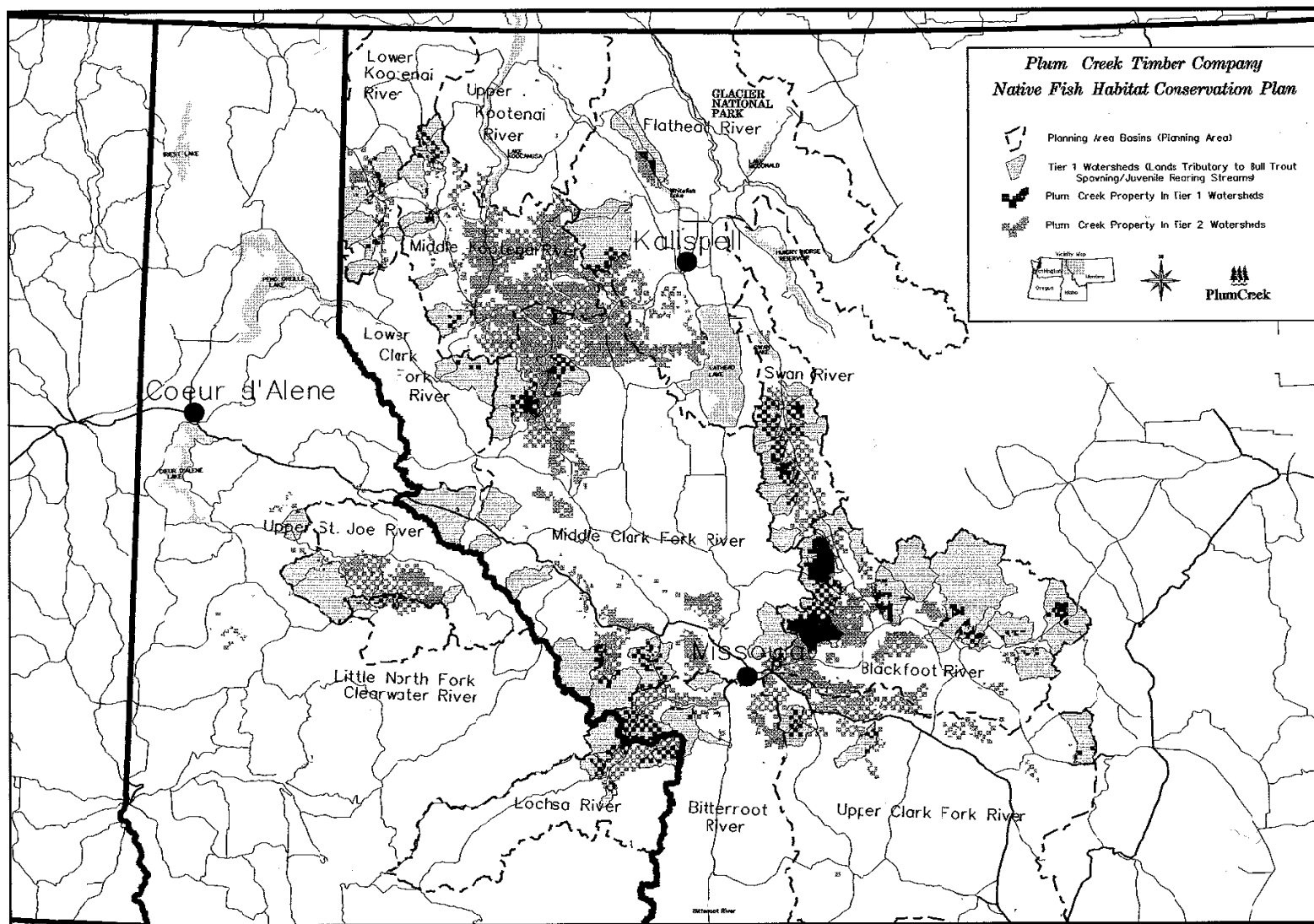
Figure 3
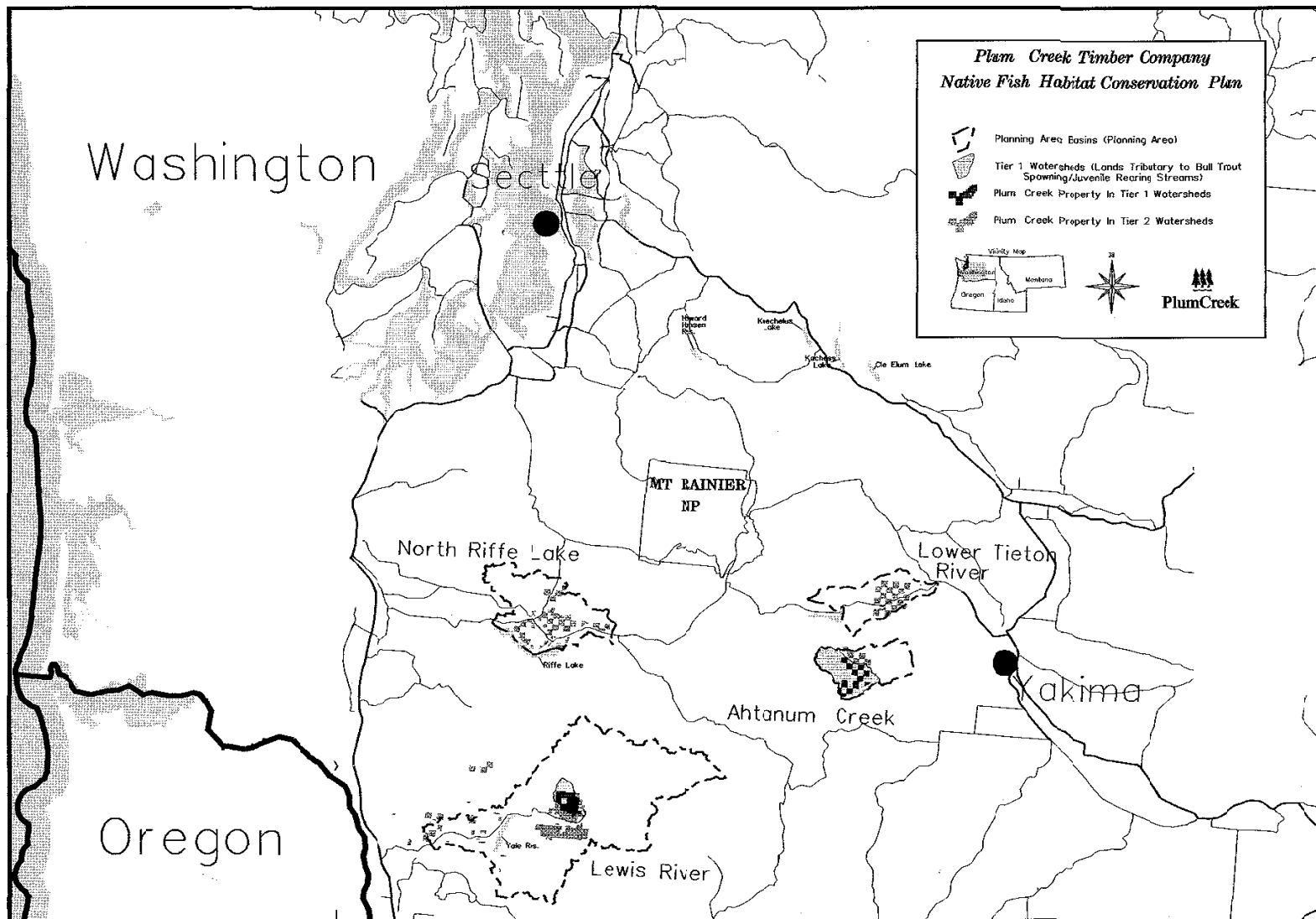Project Area and Planning Area, Montana and Idahc

Figure 4
Project Area and Planning Area, Washington

Tier 2 lands are all other Plum Creek lands that occur outside of Tier 1. Fish habitats associated with these lands may be important for other native salmonids as well as other life history stages for bull trout.

Spawning and juvenile rearing streams for bull trout occur within Tier 1 watersheds and serve to define them.

Migration and foraging streams represent streams where we know bull trout occur but are not used for spawning or juvenile rearing. These occur on Tier 2 lands.

Key migratory corridors are a subset of migration and foraging streams. The additional feature of these streams is that they are known to connect habitat where bull trout are capable of a full migratory life form. These are generally rivers or streams that bull trout use to migrate from a lake or larger river to a Tier 1 spawning stream.

2.2 NFHCP Strategy and Approach

The NFHCP strategy is based on the premise that bull trout biology (and that of other native salmonids as well) can be summarized as a requirement for the "4 Cs": cold water, clean water, complex habitat, and connected migration routes. The scientific literature suggests that forest management can affect salmonid habitat in three primary ways: increasing temperature by reduction of riparian canopy cover, increasing sediment flowing into streams, primarily from forest roads, and decreasing large woody debris by removing trees adjacent to streams that may eventually fall into the water. The NFHCP strategy is aimed at these primary variables to reduce the potential for forest practices on Plum Creek land to degrade native salmonid habitat in the future. Moreover, past land and fisheries management practices have also created some situations that may impede recovery and natural restoration of salmonid habitat. Examples of these practices include irrigation diversions, introduction of exotic fish species, and inadequate road drainage structures. Forest management practices can affect streams in "indirect" ways such as affecting hydrology and water chemistry. Some of these indirect effects, such as hydrology are likely to be detected by the monitoring of habitat variables contemplated in this plan; others, such as nutrients, with less defined causal impacts to fish are not emphasized in this plan

The NFHCP strategy also includes a focus on opportunities to identify and creatively "fix" some of these problems associated with historical management. Finally, a large landowner such as Plum Creek also engages in land management activities that are not primary forest products-oriented but have the potential to affect native salmonid habitat. Examples of these activities are livestock grazing leases and land sales. The NFHCP strategy recognizes that these ancillary land uses may represent important contributions to securing effective habitat for native salmonids and includes measures to address those

activities.

The conservation goal of the NFHCP is to create and maintain a long-term positive trend in fish habitat quality on Plum Creek lands by maintaining or reducing stream temperatures, reducing sediment delivery to streams from roads and hillslopes, and maintaining or increasing large woody debris in streams. This goal can be achieved by simultaneously improving current and future forest practices, while fixing historical (legacy) problems that are economically feasible and biologically valuable. The monitoring and research program developed with the NFHCP provides the opportunity to identify and evaluate various components of the plan. Adaptive management provides a mechanism to effect changes to the plan based on monitoring and research information.

2.3 Conservation, Enhancement, and Mitigation Measures

As part of the conservation plan, Plum Creek will formally commit to develop and implement specific conservation, enhancement, and mitigation measures in the 7 conservation commitment categories. A general description of each commitment is summarized below:

Forest Road Management - Measures would be implemented to minimize or reduce the delivery of sediment from forest roads to streams. Old roads constructed prior to the advent of BMPs that might be sources of sedimentation would be brought up to modern standards

Riparian Management -Measures would be implemented to provide adequate wood for habitat complexity, adequate canopy cover for temperature management, bank stability, nutrient inputs from litterfall, and adequate filtration for the prevention of sediment delivery to streams.

Range Management - Forested open range grazing occurs on over 40% of Plum Creek ownership in the proposed project area. Conservation measures would be implemented to minimize riparian impacts on fish habitat resulting from grazing.

Land Use Planning - Plum Creek buys and sells lands that may not be appropriate for long-term commercial forestry. Land use planning measures would be developed to mitigate the impacts of potential future development of lands within the project area sold by Plum Creek.

Legacy and Restoration - Restoration projects and "legacy management" of past management activities would be identified and implemented to mitigate impacts of past activities and restore habitat structure (e.g., large woody debris)

that is currently deficient, both forestry and non-forestry related.

Administration and Implementation - Plum Creek would track significant elements of the plan to assure compliance, and develop a program to inform and educate contractors, lessees and employees on standards and practices to be implemented.

Adaptive Management and Monitoring - Plum Creek will initiate and fund a research and monitoring program to evaluate and validate technical aspects of the plan. Information obtained in this effort will be used to modify and improve the plan over time.

3.0 Experimental Design for Adaptive Management

Adaptive management promotes aggressive experimentation with careful evaluation. The primary purpose of evaluation is to understand or "adaptively learn" about the full range of environmental responses that are possible as various actions are implemented. Valid experimental designs are needed to assess environmental responses with confidence. In this section, we describe the validity of various designs for adaptive management.

The validity of experimental designs is influenced by the degree to which a researcher can exercise experimental control, that is, the extent to which rival variables or hypotheses can be controlled or dismissed. Experimental control is associated with randomization, manipulation of independent variables, sensitivity of dependent (response) variables to treatment, and sensitivity of instruments or observations to measure changes in dependent variables. There are two criteria for evaluating the validity of any research design: (1) can inferences by drawn from the study about cause-and-effect relationships (internal validity) and (2) to what extent can the results of the study be generalized to other populations or settings (external validity)? Ideally, the researcher should select a design strong in both internal and external validity. This is not always possible, however, and of the two, internal validity is most important. Without internal validity the data are difficult to interpret because of the confounding effects of uncontrolled variables.

Different experimental designs have different capabilities for guarding against sources of invalidity. For the purposes of this paper, we describe two different research paradigms: (1) mensurative (a.k.a. descriptive or observational research, unplanned experiments)

and (2) manipulative (a.k.a. causal-comparative/experimental research, true, planned experiments) research (Table 1) (Manly 1992; Krebs 1999).

Table 1. Characteristics, types of designs, and examples of two broad types of experiments used in adaptive management.

	Designs for Passive Adaptive Management	Designs for Active Adaptive Management
Descriptions	Mensurative Experiments Observational Experiments Descriptive Experiments Unplanned Experiments	Manipulative Experiments True Experiments Causal-Comparative Experiments Planned Experiments
Characteristics	Finite sampling No randomization Inferences limited to study area	Random assignment of treatments Inferences to experimental protocol Controls
Types of designs	BACI in assessment of impact Before-After accident ANOVA designs without randomization Retrospective studies	BACI with random assignment Paired design with random assignment ANOVA designs with randomization
Examples	Effects of wildfires on riparian veg Effects of legacy timber harvest on fish habitat Effects of grazing on fish habitat Measure of fish densities Measure of redd densities Measure of stream temp above and below disturbed areas	Study of controlled and randomized grazing Study of controlled and randomized riparian-timber harvest Study of controlled and randomized treatments of LWD in streams Study of two seeding rates randomly assigned to plots

In the first case, data are collected to test hypotheses or answer questions concerning the current status of the population or setting (e.g., riverine-riparian habitat) with a certain precision and accuracy in summary statistics. Often data are collected by observing a process that may not be well understood. For example, monitoring the distribution and abundance of bull trout redds describes the current condition and trend in numbers of bull trout redds, but does not identify factors affecting the abundance and distribution of redds. That is, mensurative studies cannot tell us why redd counts increase or decrease. Because inferences cannot be drawn from these studies about causal relationships, they have low internal validity. Correlational research is a special type of mensurative research that attempts to assess whether a relationship exists between two or more variables. Correlational studies are descriptive in that it is not possible to conclude that changes in one variable are causes of change in another; there may be a third factor influencing both of the related variables. Correlational research does not establish cause-effect relationships, although it may indicate fruitful avenues of enquiry for testing of cause-and-effect.

Manipulative research, on the other hand, is used to establish cause-effect relationships. In manipulative research, the alleged "cause," the activity or characteristic believed to make a difference, is referred to as a treatment; the more general term for "cause" is independent variable. The difference, or "effect," which is determined to occur or not occur is referred to as the dependent variable. Thus, a study in which a cause-effect relationship is investigated is used to examine the effect of an independent variable on a dependent variable. In a manipulative study the researcher manipulates at least one independent variable and observes or measures the effect on one or more dependent variables. Manipulative research requires both treatment and control[4] (reference) groups. Because of the direct manipulation of independent variables, experimental research is the only type of research in which true cause-effect relationships can be established. Unlike mensurative research, these studies have high internal validity.

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[4] Lee (1993, pg 205) offers a quote that adequately describes the importance of controls in study designs. Lee writes, "One day when I was a junior medical student, a very important Boston surgeon visited the school and delivered a great treatise on a large number of patients who had undergone successful operations for vascular reconstruction. At the end of the lecture, a young student at the back of the room timidly asked, 'Do you have any controls?' Well, the great surgeon drew himself up to his full height, hit the desk, and said, 'Do you mean did I not operate on half of the patients?' The hall grew very quiet then. The voice at the back of the room very hesitantly replied, 'Yes, that's what I had in mind.' Then the visitor's fist really came down as he thundered, 'Of course not. That would have doomed half of them to their death.' God, it was quiet then, and one could scarcely hear the small voice ask, 'Which half?' (Tufte 1974, p.4--attributed to Dr. E. Peacock, Jr., chairman of surgery, University of Arizona college of medicine, in Medical World News, Sept. 1, 1974, p. 45.)"

Occasionally the independent variable cannot or should not be manipulated (e.g., large-scale deforestation) or the manipulation has already occurred (e.g., livestock grazing). In these studies, test and reference groups are correctly compared on some dependent variable with a certain precision and accuracy and valid statistical inferences are made to the difference. However, the test group differs on some independent variable (e.g., grazing) before the study begins and treatments cannot be randomized to the study units (plots). Such studies are mensurative and cause-and-effect conclusions are limited. The difference between the test and reference groups is not necessarily due to the treatment. Given that whole landscapes typically cannot be manipulated (logistically difficult, hard to replicate, and very expensive), mensurative research is used to study broad-scale patterns and trends. Because these studies do not allow the researcher to manipulate the independent variable, any cause-effect relationships established are usually tentative. However, if these studies are replicated in time and space with similar results, then cause-effect relationships can be inferred, but confidence in the inference comes from replication outside the given study area. Thus, a key difference between manipulative and mensurative research is that with the latter it is not possible to randomly assign treatments to sampling units.

Not surprising, the two research paradigms described above (mensurative and manipulative) provide managers with very different types of research data. Statistics used to evaluate data and conclusions inferred from them will vary according to the type of research conducted. Clearly, the effects of these studies on modifications to management activities will depend on the validity of the research. Below we describe in more detail how the two general types of research (descriptive and experimental) can be used in adaptive management and to what extent conclusions from the various studies can influence management objectives.

3.1 Mensurative Research
As described above, mensurative studies involve collecting data to test hypotheses or to answer questions concerning the current status of populations or settings, or to compare two or more areas where there has been no randomization of treatments. These studies include work such as bull trout presence/absence surveys, bull trout redd counts, description of existing stream and riparian conditions, Best Management Practice audits, road condition inventories, stream temperature monitoring, livestock grazing monitoring, and comparison of two or more areas. Descriptive data are usually collected through field measurements or observations, and the researcher can only measure what already exists.

Although mensurative research sounds simple, it requires careful consideration of sample size, data collection, data analyses, and what relationships and conclusions can be teased

from the data. The researcher must first describe the population from which samples will be collected. After the population has been defined, the researcher estimates sample size and describes how samples will be collected. Power analysis can be used to estimate sample size (see Cohen 1988). In general, the larger the sample size, the more representative the sample is likely to be. However, even large sample sizes can lead to biased estimates if they are not well selected. To remove sampling bias, the researcher should implement random, stratified, cluster, or systematic sampling protocols (see Cochran 1977; Levy and Lemeshow 1991; Thompson 1992). These protocols will increase the degree to which the selected sample represents the population and hence the degree to which results can be generalized (i.e., maximize external validity).

An important component of the sampling protocol is the issue of what variables to measure and how to measure them. Because time and money are limited, the researcher should give considerable attention to selecting the most efficient variables (variables that give the biggest bang for the buck). These variables should be sensitive to the research question. For example, if the researcher is concerned about the condition of the riverine-riparian habitat after timber harvest, then the variables measured should be sensitive to timber harvest (e.g., canopy cover, regeneration, stand composition, overhanging vegetation, bank alteration, bank stability, fine sediments). In addition, the researcher should select the most reliable and valid methods for measuring those variables. Here, reliability refers to the degree to which a method consistently measures the variable (accuracy and precision; standard error of the measurement) and validity is the degree to which a method measures what it is supposed to measure. For example, canopy cover can be estimated in at least three different ways: (1) a researcher can visually estimate the percentage of stream surface under canopy cover, (2) the researcher can calculate the percentage of a transect line perpendicular to stream flow that falls under canopy cover, or (3) the researcher can use a concave spherical densiometer to estimate canopy cover. Although all three methods are valid, they differ considerably in reliability. Among other things, reliability is a function of observer training, calibration of instruments, and degree of subjectivity in measurement. Depending on the research question and objectives, however, reliability may be less important than validity.

After collecting and compiling descriptive data, the researcher should describe or summarize those data using descriptive statistics. Descriptive statistics permit the researcher to meaningfully describe many scores with a small number of summary statistics. Summary statistics usually include measures of central tendency (mean, median, and mode) and variability (e.g., range, variance, deviation, coefficient of variation, and standard error). These statistics can be shown graphically or in tables. Correlations (Spearman Rho or Pearson r) are often used to describe linear relationships among variables. As stated above, correlations do not demonstrate causal-relationships,

however, they do reveal the strength of relationships among variables. Time series analysis (e.g., linear trend analysis, ARIMA, or Box Jenkins) is used to describe changes in variables over time. These analyses can identify autocorrelations and reveal increasing or decreasing trends in data. Multivariate methods (e.g., canonical correlation, factor analysis, component analysis, and cluster analysis) can be used to describe relationships and groupings of multiple variables.

Mensurative studies also allow researchers to compare two or more study areas (plots) with certain precision and accuracy. In these (*ex post facto*) studies, the researcher attempts to determine the cause, or reason, for existing differences in the behavior or status of dependent variables without randomization or manipulating the independent variable. The basic approach often involves starting with an effect and seeking possible causes. A variation of the basic approach involves starting with a cause and investigating its effect on some variable. Despite a lack of randomization of test conditions, if the test conditions are replicated spatially or temporally, a sound inference to effects may be possible. The Before-After-Control-Impact (BACI) or Interrupted Time Series with Nonequivalent Control Group design (Cook and Campbell 1979) is a special case of a mensurative study when the researcher has no control over which study area is "impacted" (see Section 3.2.1 for a more complete description of BACI designs). Similarly, a paired design might be used to contrast riverine-riparian habitat in an unmanaged forest with a previously logged area. Skalski and Robson (1992) reviewed paired designs lacking randomization. They reported that repeated measurements over time in treatment and control sites is necessary to establish the reliability of the control sites. If the responses of treatment and control sites return to "parallel" profiles, then control sites were appropriate matches. In addition, analysis of variance (ANOVA) designs can be analyzed properly in mensurative studies when treatments are not randomly assigned to units; however, valid subsampling must occur within the units. Valid statistical inferences can be drawn to the sites or units, but the authority of a randomized design is not there to prove cause-and-effect relationships (see Section 3.2.2 for discussion of ANOVA designs with randomization).

Conclusions drawn from mensurative studies describe current or existing conditions. In addition, valid statistical inferences can be drawn from BACI or paired designs that lack randomization. However, cause-effect relationships from mensurative studies are generally tentative. Because the researcher does not control the experiment (i.e., manipulate the independent variable), confounding factors and rival hypotheses reduce internal validity. Quite often, researchers attempt to conclude causal-relationships from mensurative studies. For example, one could be tempted to infer that a reduction in bull trout redd counts resulted from land-use activities near the spawning location. However, the researcher cannot be certain whether land-use activities near the spawning location or

climatic factors, angling, or downstream factors reduced the number of spawning adults. Thus, managers should carefully evaluate results and conclusions of descriptive studies before making changes in management objectives or prescriptions. Certainly, descriptive studies should be used to evaluate the status of the resource and to contrast areas over time and space. If problem areas are identified, then experimental-based studies can be conducted.

3.2 Manipulative Research

Unlike mensurative research, manipulative research seeks to test cause-effect relationships. In a manipulative study, the researcher manipulates at least one independent variable, controls other relevant variables, and observes the effect on one or more dependent variables. Manipulative studies are designed to reduce sources of external and internal invalidity. A general characteristic of manipulative research is that it is physically possible to randomly assign treatments to study units. If an invalid study design is used, one cannot determine whether the lack of response (positive or negative) in dependent variables resulted from adding an unnecessary treatment (e.g., new management prescription), or because the study design was unable to identify a true treatment effect. For example, riverine-riparian habitat may respond favorably or unfavorably to some treatments, but because these habitat parameters were not sampled consistently in treatment and reference sites for a sufficient period of time (under-replicated and hence low statistical power), the analysis may not identify significant treatment effects.

Equally important to both mensurative and manipulative research is defining the problem and population, selecting samples and measuring instruments, and measuring or observing sensitive dependent variables. Inasmuch as we discussed these issues earlier (section 3.1), we will not repeat that discussion here. However, we believe additional discussion on selection of sensitive dependent variables in experimental research for adaptive management is necessary. Frissell (pers. comm) has criticized the use of adaptive management as a means to protect aquatic habitat in part because there are long lag times in biological responses to disturbance (or treatments). In other words, the effects of disturbance or treatment may not be observed for years or decades. Therefore, it is important to measure or observe dependent variables that are sensitive to treatment. Consequently, we believe that a suite of related variables which when taken together register change quickly in response to treatments, should be given greater emphasis than biological components (fish populations), which may require several years to respond. Additionally, biological components are subject to fluctuations derived from independent factors that are difficult to control or account for (e.g., predation, fishing pressure).

In order to detect a treatment effect, manipulative experiments with randomization for adaptive management must be able to differentiate between natural fluctuations (natural variation) in dependent variables and changes that result from treatment (Christopher Frissell personal communication 1998). Valid designs should use both spatial and temporal control (reference) sites to account for natural and treatment variations (Hairston 1989; Manly 1992; National Research Council 1992; Skalski and Robson 1992). Confidence in the results is gained with spatial and temporal control and treatment sites. For example, the percentage of fine sediments may increase in a treatment site, but the researcher cannot be certain that treatment caused the observed increase without concomitant observations in appropriate control sites and random application of treatments. In fact, the observed increase in fines may reflect natural occurrences or land use activities upstream from the treatment site. We next describe two types of designs that can be used in manipulative experiments.

3.2.1. BACI Designs with Randomization

One experimental design that considers changes in dependent variables within treatment and control sites (or streams or watersheds) both before and after treatment is the BACI or Before-After-Control-Impact design (Stewart-Oaten et al. 1986; Stewart-Oaten et al. 1992; Smith et al. 1993). This type of design is also known as CTP or Control-Treatment Paired design (Skalski and Robson 1992), or Comparative Interrupted Time Series design (Manly 1992). Although names differ, these designs are essentially the same. That is, they require that data are collected simultaneously at both treatment and control sites before and after treatment. These data are paired in the sense that the treatment and control sites are as similar as possible and sampled simultaneously. Replication comes from collecting such paired samples at a number of times (dates) both before and after treatment. The pretreatment sampling serves to evaluate success of the pairings and establishes the relationship between treatment and control sites before treatment, commonly referred to as "calibration." This relationship is later compared to that observed after treatment. Unlike BACI studies introduced in Section 3.1 (mensurative research), BACI designs described here provide stronger inferences about cause-and-effect relationships because treatments and controls are assigned randomly to study units.

The success of the design depends on dependent variables at treatment and control sites "tracking" each other, that is, maintaining a constant proportionality (Skalski and Robson 1992). The design does not require exact pairing; populations simply need to "track" each other. The National Research Council (NRC 1992) reported that such synchrony occurs among populations if they are influenced by similar climatic and environmental conditions. The NRC (1992) recommended that samples in the treated reach be compared to samples in control sites in streams of the same order in the same ecoregion.

 Precision of the design can be improved further if treatment and control stream reaches are paired according to a hierarchical classification approach (Naiman et al. 1992; Watson et al. 1998). Thus, dependent variables in stream reaches with similar climate, geology, and geomorphology (geomorphic guilds) will track each other more closely than those in reaches with only similar climates.

It is important that control and treatment sites be independent. That is, the effect of treatment in one site cannot affect the dependent variables in another site. The NRC (1992) recommends that control data come from another stream or from an independent reach in the same stream. After the pretreatment period, sites to be treated should be selected randomly. Randomization eliminates site location as a confounding factor and removes the need to make model-dependent inferences (Skalski and Robson 1992). Hence, conclusions carry the authority of a "true" experiment and will generally be more reliable and less controversial. Post-treatment observations should be made simultaneously in both treatment and control sites.

Several different statistical procedures can be used to analyze BACI designs. Manly (1992) identified three methods: (1) a graphical analysis, which attempts to allow subjectively for any dependence among successive observations, (2) regression analysis, which assumes that the dependence among successive observations in the regression residuals is small enough to ignore, and (3) an analysis based on a time series model that accounts for dependence among observations. Cook and Campbell (1979) recommend using autoregressive integrated moving average models and the associated techniques developed by Box and Jenkins (1976). Skalski and Robson (1992) introduced the odd's-ratio test, which looks for a significant change in dependent variable proportions in control-treatment sites between pretreatment and post-treatment phases. A common approach includes analysis of difference scores. Differences are calculated between paired control and treatment sites. These differences are then analyzed for a before-after treatment effect with a two-sample t-test, Welch modification of the t-test, or with nonparametric tests like the randomization test, Wilcoxon rank sum test, or the Mann-Whitney test (Stewart-Oaten et al. 1992; Smith et al. 1993). Choice of test depends on the type of data collected and whether those data meet the assumptions of the tests.

3.2.2. ANOVA Designs with Randomization

Although BACI designs are powerful tools for describing cause-effect relationships, there are other manipulative designs that can be used to assess treatment effects. For example, factorial experiments, split-plot experiments, blocking, Latin squares, nested, and repeated-measures designs with randomization (Keppel 1982; Mead 1988; Manly 1992; Pukelsheim 1993) are robust ANOVA-based methods for assessing cause-effect relationships. Adaptive management may include the need to test a variety of risky or

innovative prescriptions. The case of the riparian forest is an example where several variables are used to prescribe management. Riparian prescriptions could be tested using overstory (i.e., percent cover) and stocking or residual density (i.e., trees/acre). There could be many more variables proposed (e.g., source area of LWD, distance to stream) to measure the complex process of riparian stand dynamics. In any case, ANOVA is a valid approach for testing riparian prescriptions.

During field studies the researcher may not be able to experimentally control all rival or extraneous variables. However, the researcher may be able to measure these extraneous variables during the study and then use analysis of covariance to remove their influence on the dependent variable. Analysis of covariance is an ANOVA-based design that allows the researcher to compare group means on a dependent variable, after these group means have been adjusted for differences between the groups on some extraneous (covariate or concomitant) variable. Because analysis of covariance is a combination of regression analysis with an ANOVA, the dependent variable must be related to the covariates. Analysis of covariance is used to: (1) increase precision (power) in an experiment, (2) control for extraneous variables, and (3) compare regressions within several groups (Dowdy and Wearden 1983). For example, suppose a researcher is interested in comparing retention of LWD in stream channels that are treated with different riparian harvest prescriptions. Suppose also that retention of LWD in a channel is related to the amount of LWD stored in the channel at the beginning of the study. That is, the more LWD in the stream channel, the more likely recruited LWD will be retained. In this example, the dependent variable is volume of LWD at the end of the study and the covariate is the volume of LWD at the beginning of the study. Analysis of covariance would adjust the means of the dependent variable (LWD volume) on the basis of the covariate means, and then compare these adjusted means to assess differences among treatment groups. Thus, the researcher is able to "statistically" control any initial differences that may be present and that may confound differences among treatment groups.

In the above example, the researcher used the same instrument to measure the covariate and the dependent variable. That is, both the covariate and dependent variable were the same variable (volume of LWD). In contrast, it is possible for the covariate and the dependent variable to be different variables. Here, the covariate and dependent variables are obtained by different measurements. For example, a researcher may be interested in assessing the effects of different riparian harvest prescriptions on stream temperatures (dependent variable). However, extraneous variables such as elevation, stream size, aspect, and azimuth affect stream temperatures independent of the treatment. If the researcher is unable to control for these factors in the study design (e.g., stratification or blocking), the researcher may be able to remove their effects statistically. That is, if

these variables are related to temperature but not to each other, analysis of covariance may be used to adjust mean temperature scores. In this example, the dependent variable (stream temperature) and covariates (elevation, stream size, aspect, and azimuth) are not the same variables. Although this is a simple example of the use of analysis of covariance, covariance can also be used in factorial analysis, repeated measures analysis, and even multivariate analysis. We caution that analysis of covariance is no substitute for good experimental design.

The success of both mensurative and manipulative research designs described in Section 3.0 depend on a sound sampling program. Control of the sampling program must be maintained throughout the period of study. Changes in the sampling program should be avoided (e.g., changing sampling techniques, adding or dropping sampling sites, or changing the time when annual samples are collected). In addition, it is important not to overemphasize statistical significance (as opposed to biological or economic significance), because statistical significance is tied to sample size, alpha-level, capture probabilities, magnitude of the treatment, magnitude of temporal variance, and temporal covariance between reference and treatment sites through time (Skalski and Robson 1992). In many cases we believe it is better to emphasize the use of point estimates and confidence intervals rather than strict tests of significance. Understanding discussions about biological significance versus statistical significance is easier if results are presented in terms of confidence intervals on differences, ratios, and odds ratios. We believe biological significance, based on valid experimental design and tempered by biological interpretation, is paramount in assessing treatments and making management decisions. Clearly, results of valid experimental research should be used to evaluate management objectives and prescriptions.

3.3 Policy and program implications

Development of affordable monitoring programs for adaptive management will involve substantial, scientifically risky innovation in methods and approaches (Walters 1997). Walters and Green (1997) identified 4 key ingredients needed to quantify value comparisons among policy alternatives:

- Universe of inference or application: scientists and managers need to be less vague about just how large the "universe of inference" is for adaptive management experiments, i.e., how wide the range of future situations might be to which experimental results will be applicable.
- Treatment options: experimental management generally involves comparing some innovative treatment options to a baseline or routine management practice. There is generally no easy answer to the question of where the options come from in the first place and what should be viewed as the appropriate reference or baseline treatment. This generally derives from the imagination of individuals or the result of

negotiations between stakeholders.
- <u>Impact hypotheses and baseline policy option</u>: to quantify the expected value of a management experiment, it is necessary to specify a reasonable range of possible outcomes. This may require the necessity to "expect the unexpected".
- <u>Value measures</u>: developing an objective and effective process for "bottom-line" comparisons of policy options.

Walters (1997) warns that reducing experiment sizes (e.g., variety of treatments, replication, duration, complexity of monitoring set) rather than investing in innovative monitoring approaches (e.g., developing cooperative working arrangements to acquire field data) constitutes a "false economy" and will have dire future consequences. He recommends replicating experiments to the maximum extent practicable and finding ways to reduce the expense of gathering data at each site by minimizing the kinds of measurements and using rapid assessment techniques to economically acquire data.

The TFW Effectiveness Monitoring and Evaluation Program will be developing study design guidelines for site-specific and watershed level monitoring projects in the following areas (Shuett-Hames et al. 1998):
- a system of situational categories
- specific monitoring questions and hypotheses.
- standard criteria and procedures for evaluating effectiveness.
- guidance on sampling design, data analysis and interpretation.

It is expected that "cross-pollination" between research and monitoring sponsored by TFW and the NFHCP will be applicable and beneficial to both efforts.

4.0 Perspectives for Adaptive Management in the Native Fish HCP
Summarized below are a wide range of potential adaptive management projects that have been envisioned by the authors. Specific elements of a monitoring and research program that comprise the adaptive management component of the NFHCP could be selected from this list. The actual selection of projects would be based upon cost and operational effectiveness as well as the specific uncertainties of the Services and Plum Creek. **Table 2** summarizes each of the 15 potential projects and how they each relate to the general conservation areas of the NFHCP.

Table 2. Summary of 15 potential research and monitoring projects for the Plum Creek Native Fish Conservation Plan and their relationship to mitigation measures specified in the HCP. The actual selection of projects would be based upon cost and operational effectiveness as well as the specific uncertainties of the Services and Plum Creek

| Subject Area	Project Type	Project Title	Project Description
Roads	Continuous Improvement Monitoring	**A1**. Road Condition Tracking System	Maintain computer database of road BMP and closure status, as well as surplus and abandoned roads.
Riparian & Roads	Continuous Improvement Monitoring	**A3**..NFHCP Implementation Monitoring	Conduct annual audits of road BMP implementation and riparian prescription audits with internal and 3rd parties
Roads	Continuous Improvement Monitoring	**A2**. Road Condition Inspections	A commitment to inspect company roads to include in the Road Condition Tracking System (A1 above)
Roads	Experimental Management	**B1**. Effectiveness of NFHCP road management strategies at reducing levels of in-stream fine sediment	Determine if improving road BMP upgrades and other sediment reduction components of the NFHCP actual result in changes in instream conditions over time.
Riparian	Experimental Management	**B2**..Evaluation of the effectiveness of NFHCP riparian management strategies for maintaining natural levels of in-channel LWD	Inferential design to "monument" and measure LWD loads over long term at selected reaches Inferential design for repeated measurements in "demonstration watershed" where an array of prescriptions will be simultaneously tested
Riparian	Basic Research	**C3** Riparian forest stand dynamics	Investigate LWD recruitment rates and processes, forest growth and mortality. Results relate to basic assumptions in FVS and RAIS models Descriptive design to validate assumptions used in RAIS model (e.g. tree fall angle; bank erosion)
Riparian and Biological	Continuous Improvement Monitoring	**A6** Bull trout redd monitoring	Descriptive design to annually monitor bull trout redds in 3 Swan River tributaries in conjunction with MDFWP program

Table 2 (Concluded).

Subject Area	Project Type	Project Title	Project Description
Riparian	Experimental Management	**B3**. Evaluation of the effectiveness of NFHCP riparian management strategies at maintaining maximum water temperatures close to background	Implement a BACI design to evaluate water temperature changes associated with riparian harvest prescriptions.
Riparian	Experimental Management	**B4** Use of aquatic ecoclassification for enhanced protection of aquatic resources within the NFHCP project area	Use descriptive and inferential designs to group geomorphic guilds into riparian "super-guilds and relate them to channel sensitivity and fish habitat vulnerability
Grazing	Continuous Improvement Monitoring	**A4** Grazing Lessee Monitoring	Monitor the grazing leases for compliance with BMPs
Grazing	Continuous Improvement Monitoring	**A5** Grazing Year End Reporting	Year end evaluation of grazing riparian management plans (RMP)
Grazing	Experimental Management	**B5** Long-term Effectiveness of Plum Creek's Grazing BMPs	Establishing a monitoring plots to determine if implementation of Grazing BMPs is resulting in improved riparian conditions over time. Information will be used to periodically update the BMPs.
Restoration	Experimental Management	**B6** Effectiveness of riparian restoration on mainstem key migratory rivers	Beginning with Thompson River project, develop study to evaluate progress of riparian restoration in achieving desired future condition over short or long term timeframes
Restoration	Basic Research	**C2** Effectiveness of riparian management strategies to accelerate the growth from stagnant and young, overstocked stands	Evaluate effectiveness and economics of thinning overstocked stagnated riparian timber to achieve desired future conditions
Restoration	Basic Research	**C1** Gold Creek experimental brook trout suppression project.	Explore feasibility of reducing brook trout in areas where they compete with bull trout

4.1. Monitoring and Research Topics for the NFHCP

As details of the NFHCP have been developed by Plum Creek with technical advice of the Services, it becomes evident that the level of "certainty" regarding basic biological relationships and conservation measures contemplated in the HCP fall within a "continuum" ranging from highly confident to highly speculative (**Figure 6**). To capture this notion of a "certainty continuum", we consolidated elements of the adaptive management and monitoring component of the HCP into three general categories:

- Continuous Improvement Monitoring
- Experimental Management
- Basic Research
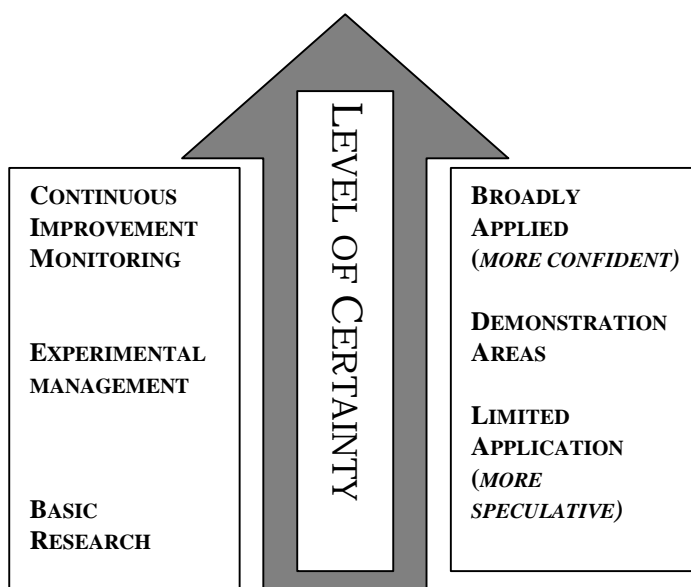
Figure 5. The "certainty continuum" showing categories for research and monitoring projects in the NFHCP.

Summarized below are more detail on these categories and descriptions of activities that will likely be included in the final HCP. Additional projects and activities may be added to this list as discussions with the Services, scientific community, and general public progress. It is important to note that the authors have made their best effort to work out the details of these projects, yet there are numerous details that have yet to be finalized and could substantially change the scope, approach and expense of these projects.   In addition, some of these projects may be combined. More consultation with the scientific community may be necessary to complete these details.

4.1.1 Continuous Improvement Monitoring (CIM)

Continuous improvement monitoring refers to elements and activities of the NFHCP that are done often through the HCP period (many on an annual basis) and generate information that can be quickly assimilated into management for corrective action if necessary. These activities generally address areas of low "uncertainty" and do not require elaborate or complex study designs or large investments of capital. Continuous Improvement Monitoring is analogous to the "implementation monitoring" described by the Upper Columbia River Basin Planning Team and "selective monitoring" as described by Environmental Protection Agency (USFS and BLM 1997, USEPA 1988). Because these topics relate to improving "day to day" management, results are not envisioned to lead to HCP amendments. CIM projects include the following:

A1. **Road Condition Tracking.** Plum Creek will develop and maintain a database that quantifies the Best Management Practice (BMP) and closure status of all project area road segments. This same system will be used to inventory roads that are surplus to our management needs or have been abandoned. The goal is to track key elements of road condition and provide a concise summary of progress in upgrading old roads to current BMP standards and correcting "hot spot" areas where specific problems have been identified that could introduce unacceptable levels of sediment into streams. Total roads in the database will represent roads for which Plum Creek has or shares management responsibility. Each road segments will be assigned one of the following categorized based on forester field inspections:

1. Meets BMPs

2. Does not meet BMPs

3. "Hot Spots" (specific problem areas)

4. Not Verified

A2. **Road Condition Inspections** . Plum Creek will inspect roads to determine their BMP status and condition. Plum Creek foresters will perform the road inspections, and results will be included in an annual update of the road database. Orphan roads discovered during the inspection process will be identified, mapped, inspected, and added to the database. Surplus roads and road closure status will also be identified at this time. Substantially all of Plum Creek's road system will be inspected within five years of plan implementation.

A3. NFHCP Implementation Monitoring of Road and Riparian Prescriptions the implementation of conservation measures finalized in the HCP will be monitored on an annual basis. Measures of particular interest for this effort include implementation of riparian prescriptions and forestry BMPs related to road construction and drainage. Forestry BMP audits are a continuation of a program already underway to conduct internal audits to supplement state BMP audits that quantify BMP application and evaluate BMP effectiveness. The riparian component of this project will focus on the application and effectiveness of riparian prescriptions applied in sensitive stream reaches described in Light et.al. (1999) and specified in the final NFHCP. Riparian prescription audits will be completed internally and in conjunction with external 3rd party audits for compliance with Plum Creek's environmental principles. Information and results of implementation monitoring will be shared annually with the Services and summarized for mandatory reporting dates as specified in the NFHCP implementation agreement. See Table 3 for details on a possible schedule for implementation reporting.

A4. Grazing Lessee Monitoring. As part of Plum Creek's Grazing BMPs, leaseholders monitor stream and riparian conditions at several sensitive locations on their allotment at least twice each grazing season. Monitoring involves filling out a simple form and taking photographs at established points. This information is submitted to Plum Creek in the fall. This information is used to give annual feedback on the success of the grazing strategy at maintaining or improving riparian conditions. This is intended to be leaseholder implementation monitoring (verified by Plum Creek) and not rigorous scientific research. A more detailed study is proposed to evaluate the effectiveness of Plum Creek's Grazing BMPs (See project B5).

A5. **Grazing Year End Reporting**. Each year leaseholders prepare a range management plan (RMP) that describes the management system that will be implemented during that grazing season to achieve Plum Creek's environmental objectives. At the end of the grazing season, the lessee completes an "End of Year Report" that describes what worked well during the grazing season and what did not with regard to environmental

compliance. This information in conjunction with monitoring in A4 is used to determine what should be modified in the next years RMP. The kinds of feedback that are to be addressed in the report are answers to the following questions:

- Were Plum Creek performance standards met across the entire lease? If not, why?
- Were environmental concerns effectively addressed>
- Was pasture and livestock management implemented according to the RMP?
- Were planned range improvements implemented according to the RMP?
- What changes will be made to the next years RMP to continue improvements in range conditions and compliance with performance standards?.

A6. Bull Trout Redd Monitoring. This study consists of monitoring bull trout redds densities in specific index reaches in the Blackfoot and Swan River drainages as an indicator of bull trout population trends. This is a long term monitoring project intended to be generally reflective of bull trout conservation efforts implemented by Plum Creek and other land and fishery managers for specific metapopulations.

4.1.2 Experimental Management

The experimental management category includes those issues and activities that represent "significant scientific uncertainty" in the NFHCP and can be subjected to a more rigorous study design. These topics can be viewed as "applied research" whereby models can be tested, and innovative or untested management practices can be evaluated. Experimental management includes both the "effectiveness" and "validation" monitoring described by the Upper Columbia River Basin Planning Team (USFS and BLM 1997).

In many cases, experimental management studies are envisioned to be conducted at two scales: Extensive, and Intensive. The extensive studies would obtain feedback across the entire project area (e.g., long-term trends in fine sediment levels in randomly selected lower-gradient stream reaches). This information can be rapidly collected, but because of the scope, is not well suited to inferring cause-effect relationships. The intensive studies will be done in a handful of "Demonstration Watersheds" are designed to establish cause-effect relationships. These watersheds may be selected among the dominant geomorphic/climatic/geologic settings in the project area (see Watson et al. 1998 for how this might be done). Experimental management projects include the following:

B1. Effectiveness of NFHCP Road Management Strategies at Reducing Levels of Instream Fine Sediment. A majority of Plum Creek's road system in the NFHCP area was constructed prior to the implementation of Watershed Best Management Practices in 1989 (see Sugden and Light 1998). As such, road drainage is inadequate on much of the road network, the result being elevated delivery of fine sediment to streams (McGreer et al. 1998). This can be dramatically reduced by addition of road drainage features around streams that direct sediment-laden runoff into filtration areas before entering streams. One component of the NFHCP will be a commitment to bring a high percentage of Plum Creek's road system up to current BMP standards over the first 10 years of the plan. This action is projected to reduce delivery of fine sediment to streams from roads on the order of 40-60% (McGreer et.al.1998) The purpose of this project is to monitor levels of in-stream fine sediment over time in order to detect an in-stream response to the projected decrease in sediment supply from roads.

B2. **Effectiveness of NFHCP Riparian Strategies at Maintaining Natural Levels of In-Channel LWD.** The maintenance and enhancement of large woody debris levels within streams is a primary objective of riparian prescriptions developed in the NFHCP (Light et.al. 1999). Adaptive management is an important step in the process of matching riparian management prescriptions to LWD objectives (**Figure 7).** The purpose of this project is to examine to what extent NFHCP riparian commitments maintain LWD loads. The project will likely involve the designation of "demonstration areas" where various riparian buffer designs will be implemented with monitoring of LWD levels in stream reaches to compare actual recruitment rates compared to those predicted by the Riparian Aquatic Interaction Simulator (RAIS) model (Light et al. 1999). A long-term objective of the study will be to lessen dependence on the RAIS model as experience and information with the field-tested experimental designs increases. When implemented, this study will likely be combined with others (such as B3).

B3. Effectiveness of NFHCP Riparian Management Strategies at Maintaining Maximum Stream Temperatures Close to Background. Riparian harvest prescriptions developed as part of the NFHCP are expected to result in little or no reduction in canopy (shading) over streams. As such, maximum water temperatures are not expected to significantly change. The objective of this study is to verify the efficacy of NFHCP riparian prescriptions in maintaining maximum water temperatures close to background levels. Continuous summertime water temperatures above and below timber harvests that border perennial streams will be measured, both before and after harvesting. Data will also be collected on a variety of stream and riparian attributes that can assist in stratifying the sample sites and explaining any observed changes.

Channel Sensitivity

For Fish-Bearing Streams	High	Mod.	Low
Tier I	Rx "A"	Rx "B"	Rx "C"
Tier II	Rx "D"	Rx "E"	Rx "F"

Species / Life History Stage Vulnerability

Prescriptions A-F are developed to achieve management objectives (e.g., target in-channel LWD loads) for different channel sensitivities in Tier I and Tier II basins.

No → Enhancement Opportunities? •Accelerate LWD recruitment • In-channel placement

Is Stand Harvestable? **Yes**

N pre-determined Rx (based on *x* harvestable stand types, plus 1 no-harvest Rx for non-harvestable stand types)

Select Pre-Determined Rx to Match Revised LWD Objectives

Develop New Rx (rare cases)

Yes

Are available Rx Adequate to Achieve Objectives?

No

Yes

GUILD CHECK

Has Guild Work been Completed for this area?

If so, are revisions to targets warranted? (I.e., other channel sensitivities, spp / LH vulnerabilities)

Adaptive Management (Monitoring and Research)

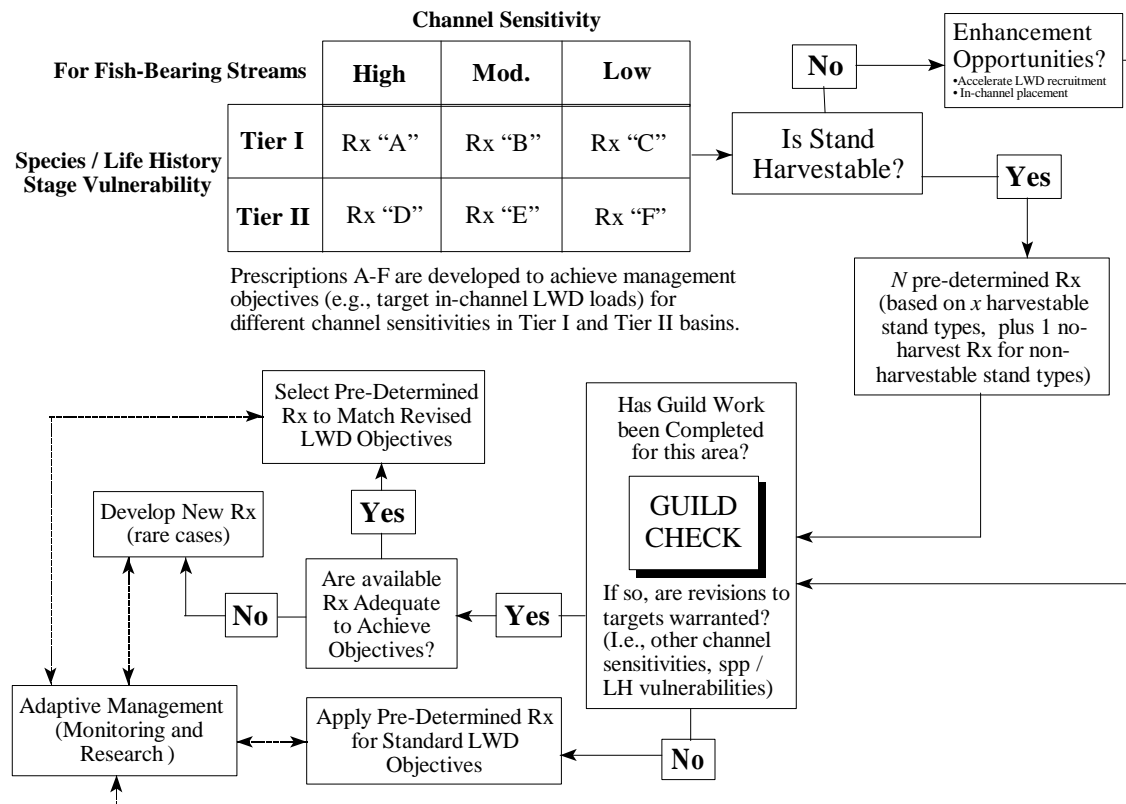Apply Pre-Determined Rx for Standard LWD Objectives

No

Figure 6. Process for selecting riparian management prescriptions for streams (from Light et al. 1999)

B4. Use of Aquatic Ecoclassification for Enhanced Protection of Aquatic Resources within the NFHCP project area. This project develops the technique to delineate riparian "superguilds" across the NFHCP area, which exhibit similarities in physical characteristics, fish species use, and sensitivity to land management activities. The development of these superguilds within large geomorphically similar areas will facilitate a less costly watershed analysis process that can be reliably extrapolated to other drainage basins, resulting in a further reduction of the risk of land management to native salmonids (Watson et al. 1998). Figure 8 illustrates the process to develop and evaluate riparian superguilds as a tool to further refine riparian management prescriptions. Effectiveness monitoring is an important step in this process.

B5. **Long Term Effectiveness of Plum Creek's Grazing BMPs**. Over 90% of the NFHCP project area is in open range and 43% falls within a grazing lease or allotment. Cattle grazing is an annual activity that can have dramatic short and long-term effects on riparian areas and fish habitat. This study will build a knowledge base by which the long-term effectiveness of Plum Creek's Grazing BMPs can can be evaluated, and serve as a basis for BMP modification over time. A network of monitoring plots will be established to evaluate the long-term effectiveness of Plum Creek's Grazing BMPs at maintaining or improving riparian conditions and fish habitat. Various treatments will be assigned to study plots and results monitored every five years. Information obtained from the plots will be used in 5-year reviews of the grazing BMPs. This rigorous scientific study will complement the semi-annual riparian monitoring conducted by grazing lessees (See A4).

B6. Effectiveness of Riparian Restoration on key Migratory Rivers. The NFHCP project area contains 112 miles of Key Migratory Rivers (corridors) on Plum Creek land important to native salmonids. A commitment of the NFHCP is to identify and implement enhancement projects in these migratory corridors which can remove some "legacy" impediments to native salmonid recovery. Plum Creek will monitor the trend in riparian/stream condition and fish habitat along Key Migratory Rivers where riparian restoration activities have been implemented to obtain feedback on the success of the program. This study will involve collecting riparian and habitat data on randomly selected treatment (impact) and control stream reaches.
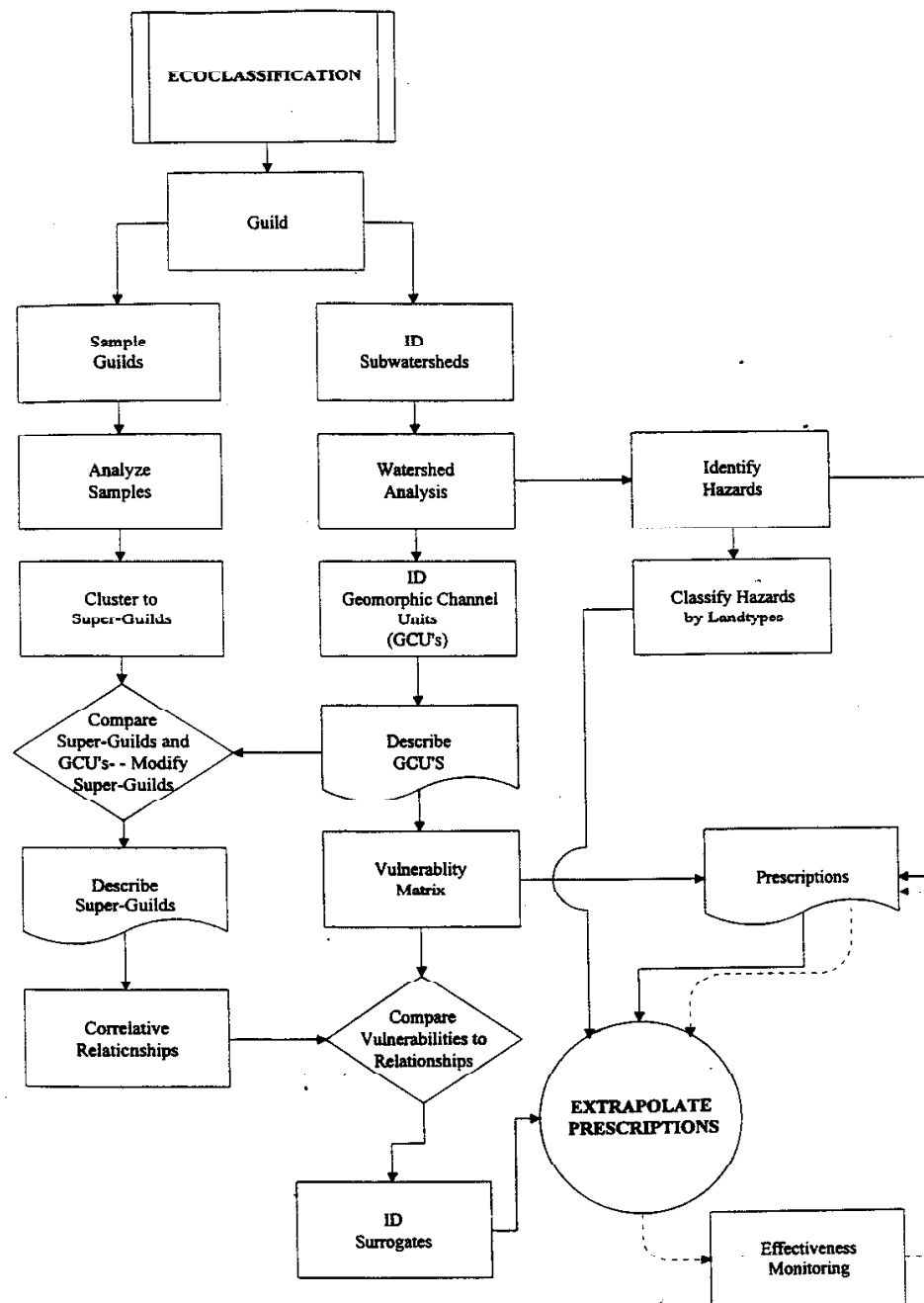
Figure 7. Process to develop and evaluate riparian superguilds as a tool to further refine riparian management prescriptions.

4.1.3. Basic Research

The basic research category includes projects where relationships are more speculative at present. Objectives are aimed at establishing cause and effect relationships between forest management activities and resource concerns before substantive management and mitigation measures can be initiated. Projects included in this category involve the development of new techniques such as brook trout suppression methods, and evaluation of the economic feasibility of thinning overstocked riparian timber stand to accelerate the development of desired future conditions. The basic research category overlaps the concept of "baseline" monitoring discussed by the Upper Columbia River Basin Planning Team (UCRB Draft EIS 1997) in that projects may be looking at fundamental growth and mortality rates of trees to evaluate assumptions used in tree growth models.

C1. **Gold Creek Experimental Brook Trout Suppression Project.** Gold Creek, a tributary of the Blackfoot River, is a tier 1 watershed that supports a spawning and rearing population of bull trout and westslope cutthroat trout. High densities of eastern brook trout also exist where they were historically stocked in low gradient reaches of the drainage. The objectives of the project are to evaluate the success of exotic species suppression efforts in terms of the applicability to conservation and restoration of populations of native salmonids. On selected study reaches, brook trout captured during multi-pass electrofishing will be euthanized and disposed of. The initial phase of the project will be to evaluate the biological and economic efficacy of the approach. If the project proves successful, the technique will be more widely applied in the NFHCP area in cooperation with state fisheries agencies.

C2 Evaluation Of The Effectiveness of NFHCP Riparian Management Strategies to Accelerate the Growth from Stagnant and Young, Overstocked Stands.
Approximately 13% of Plum Creek land the NFHCP planning area is identified as riparian stand type "H3"-densely stocked small-sized conifer stands with 300-700 trees per acre. These stands have little conservation value in their present state because the overstocked nature of these stands reduces the growth rate and retards the time when these stands could be contributing meaningful large woody debris and shade to fish bearing streams. The purpose of this project is to examine to what extent NFHCP riparian commitments can accelerate the growth from stagnant and young, overstocked stands. Data will be collected from permanent sample plots established in H3 stands. Changes in volume growth, height and diameter will be measured following regional standards. Riparian characteristics (e.g. canopy closure, tree mortality) will be gathered at the study reaches before and after treatment.

C3 Validation of the Forest Vegetation Simulator (FVS) for Riparian Forest Stand Development. The Forest Vegetation Simulator model provides the basic assumptions of how riparian forest stands grow and develop in the NFHCP. FVS provided basic growth data which was used in the RAIS model to estimate the amount of wood that could be contributed to the stream over time for 9 different riparian forest types (Light et.al.1998). The purpose of this study is to examine the extent riparian silviculture accelerates the forest growth and development of critical riparian functions. The objective establishes confidence in the predictions and use the information to adjust riparian management strategies where goals (e.g. stand development targets) are not achieved. This is not a calibration of the FVS model, which would require re-fitting of the growth equations and is a far more intensive effort. The data from this project could be used in a larger, multi-organizational initiative that would calibrate the FVS model for riparian forest types. Measurements will be taken from reference reaches and the associated riparian forests. Permanent plots will be periodically re-measured to assess performance of the model system.

4.2. Consultation with Services

Information obtained in the research and monitoring projects outlined here will be used by Plum Creek and the Services during the 30-year permit period to address the following 3 areas of plan administration:

- **Effectiveness of the mitigation measures**-are techniques developed and tested in the HCP to address issues such as buffer designs to maintain water temperatures and operations to eradicate undesirable or competing exotic fish species successful?

- **Changes in environmental baselines**-have external conditions such as habitat quality on federal lands or biological trends in bull trout redd counts changed that might exert positive or negative influences on the NFHCP?

- **Achievement of desired biological objectives-** can the positive trends in temperature, sediment and large woody debris levels be documented for the NFHCP area?

As shown in **Table 3**, administration of the monitoring and research program for the NFHCP requires frequent and close association with the Services. Projects will be sequenced to provide information prior to mandatory reporting periods with the Services. In addition, the initiation of projects is designed to provide more information at the "front end" of the 30-year HCP permit period when uncertainty and impacts may be most likely, and potential changes would be most advantageous to adaptive management.

Table 3. Monitoring Matrix for Plum Creek 30 year Native Fish Habitat Conservation Plan. Will be revised in the NFHCP based on discussion with Services.

Shaded Columns are Mandatory Report Years to USFWS / NMFS

Topic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Actual year (2000)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Continuous Improvement Monitoring																														
Road Database	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Implementation Monitoring	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Road Condition Inventories	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Grazing lease monitoring	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Riparian grazing evaluation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bull Trout redd counts	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Experimental Management																														
In-channel BMP effects		X	X	X	X																									
LWD Recruitment	X	X	X	X	X					X					X					X					X					X
Temp & Harvest Designs	X	X	X	X	X					X					X					X					X					X
Ecoclass & Guilding	X	X	X	X	X	X																								
Grazing plots	X	X		X				X					X					X												
Riparian Restoration Effects	X	X			X					X					X					X					X					X
Basic Research																														
Brook Trout Suppression	X	X																												
Riparian Thinning	X	X	X		X					X					X					X					X					X
Riparian Forest Dynamics	X	X	X	X	X					X					X					X					X					

5.0 Summary and Conclusions

Adaptive management is a philosophy that is more easily understood than implemented. It is more than good science and good economics. It requires an admission of uncertainty and a commitment to innovation. One of the strengths of adaptive management is what educators call the "principle of self-discovery" or the propensity for people to change behavior when they devise the arguments to do so for themselves rather than have the arguments imposed by other people (Walters 1986). The notion of adaptive management as "learning by doing" is well suited to Habitat Conservation Plans, which can be viewed as management "experiments".

Dynamic tension between the need to change management based on valid new information and the "No Surprises" policy that limits the liability of landowners for committing more land and money should not be a barrier to effective adaptive management. Adaptive management can be an effective way to address the areas of significant scientific uncertainty in HCPs. Although approaches outlined for adaptive management in HCPs can open the door for interagency cooperative research, it is important to note that the responsibility to fund and complete research and monitoring in HCPs is borne solely by the applicant. However, despite potential limitations, information and experience obtained through effective adaptive management in HCPs can be compounded many times and provide essential contributions to our knowledge of ecosystem management.

To be most effective, adaptive management projects must include three components:

1. clear objectives and testable hypotheses that relate back to substantive components of the plan,
2. credible design and methodology, and
3. a contingency plan for changing management in response to new information.

Admittedly, the decision of when the deviation between expected performance and actual achievement becomes great enough to resort to the contingency plan is one of the most challenging aspects to adaptive management. In the HCP process, this must be agreed upon between the applicant and the Services. The deviation will vary according to the precision of the measurements or model as well as the importance of the issue. It is also desirable to scale the correction effort to the extent of deviation from the desired outcome. For the NFHCP, this refinement has yet to be included in the projects described here.

The 15 adaptive management projects identified thus far in the NFHCP fall under three categories, depending upon the degree of complexity and certainty. Six projects can be considered "continuous improvement monitoring" since they are low risk but high return investments, the data from which can be immediately used to adjust management activities. Many of these activities involve annual database updates and inspections. Six of the projects fall under the category of "experimental management" and incur more rigorous design due to the higher degree of complexity and uncertainty involved in model validation and more intricate sampling. Three projects fall under the category of "basic research" due to their more speculative nature and lack of understanding. These latter projects address areas contemplated by the HCP but for which cause-effect relationships are poorly understood.

It is important to have several criteria in mind when selecting the final array of research and monitoring projects to support an adaptive management program. Advice from experts in this field suggest that topics for inclusion should be reduced to significant "big ticket" items where replication can be increased and the kinds or number of measurements can be decreased for cost efficiency (Carl Walters, personal communication 1998). For the NFHCP, we recommend consideration of the following criteria:

- the project must improve the level of "certainty" in the HCP mitigation measures

- the project must address the "4 C's" of cold, clean , complex and connected water

- the project must consider the magnitude or potential risk to the species

- the project must be cost-effective

- the project must relate to a major item in the HCP that entails large costs or significant uncertainty

- the project must be able to be credibly investigated with appropriate technology and design

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Appendix 1:

NFHCP ADAPTIVE MANAGEMENT PROJECT SPECIFICATIONS

NOTE: THE PROJECTS DESCRIBED IN APPENDIX 1 REPRESENT THE CURRENT RECOMMENDATIONS OF THE AUTHORS. THE NUMBER AND NATURE OF THESE PROJECTS MAY CHANGE IN RESPONSE TO ADDITIONAL DISCUSSIONS WITH THE SERVICES AND THE SCIENTIFIC COMMUNITY.

Project Title: **A1. Road Condition Tracking**

Description: This project involves developing a GIS database that delineates and quantifies BMP status of all project area road segments for which Plum Creek has or shares management responsibility. This study links to NFHCP Technical Report #3, and is associated with several road management commitments in the plan.

**Purpose &
Objectives:** Plum Creek has about 20,000 miles of forest roads in the NFHCP planning area, many of which were constructed prior to the advent of Forestry Best Management Practices (BMPs). Plum Creek has a geographic information system (GIS) that contains the locations of these roads. However, we do not have a system for tracking road BMP status in our GIS. The objective of this project is to develop a system that is compatible with our GIS for keeping track of the BMP status of roads in the planning area.

Hypothesis: Not Applicable

Type of Study: This study can be considered descriptive since it is not intended to document any specific cause-and-effect relationships. This project is classified as continuous improvement monitoring.

Approach: All roads that Plum Creek has or shares management responsibility will be assigned one of the following categories:

- Field-Verified In Compliance
- Field-Verified Out of Compliance
- Hot Spot
- Not Verified or Unknown

In addition, road closure status will also be tracked. Roads that are surplus to Plum Creek management needs, or have been abandoned will also be tracked with this sytem.

Use of Results: Information contained in the road database will be used for a number of uses by a number of individuals. Data will be used by Plum Creek foresters to inventory and prioritize areas for BMP improvement. Results will be used by Plum Creek management for NFHCP implementation agreement (IA) reporting. Results will be used by scientists to compare with results obtained from detailed road sediment delivery analyses, and for other programs (such as development of Total Maximum Daily Loads under the Clean Water Act).

Cost Estimates: The cost of keeping the database up-to-date will involve approximately ten weeks of Plum Creek GIS personnel time annually. This does not include the time necessary for conducting road condition inventories by foresters (A2).

Timetable: This database will be in operation at the start of the NFHCP and last throughout the life of the plan.

Project Title: **B1. Effectiveness of NFHCP road management strategies at reducing levels of in-stream fine sediment.**

Description: The vast majority of Plum Creek's road system in the planning area was constructed prior to the advent of forestry Best Management Practices (BMPs). As such, road drainage is inadequate on much of the road network, the result being elevated delivery of fine sediment to streams. This can be dramatically reduced by addition of road drainage features around streams that direct sediment-laden runoff into filtration areas before entering streams. One component of the NFHCP will be a commitment to bring a high percentage of Plum Creek's road system up to current BMP standards over the first 10 years of the plan. This action is projected to reduce delivery of fine sediment to streams from roads on the order of 40%-60% (See McGreer et al. 1998). This project will monitor levels of in-stream fine sediment over time in response to the projected decrease in sediment supply from roads.

Purpose & Objectives: The purpose of this study is to determine trends in surface fine sediment in streams over the life of the NFHCP and relate these trends to implementation of Plum Creek's forest management activities, particularly the NFHCP commitment to bring old roads up to current BMP standards.

Hypothesis: In-stream levels of fine sediment will decrease over time in response to reducing fine sediment supply from forest roads.

Type of Study: This study is experimental research, since we are attempting to infer a cause-and-effect relationship, and is classified as experimental management.

Approach: Two levels of investigation are proposed:

The first level of investigation involves monitoring fine sediment levels in streams throughout the project area over time. In fourth-order watersheds where Plum Creek is the predominant landowner, a GIS-based analysis will be undertaken which will identify perennial low-gradient stream reaches (1-4%) by meta-ecoterra. Stream reaches will then be randomly selected for sampling. Stream reaches to be sampled will be monumented in the field and sampled for the surface fine fraction. The exact monitoring approach has not been determined, but would likely involve a streamlined pebble count approach. Sample size (sample power) could be estimated based on the variance in ocularly-estimated fine sediment levels in low-gradient streams in the Swan and Thompson River Basins (where data already exist). If we used this approach, we would have to assume that the variance in ocular estimates of fine sediment was similar to the variance in fine sediment measurements by pebble counts. In addition to treatment sites, streams would also be monitored in watersheds for which BMP improvements will not be accelerated (controls), and watersheds that represent relatively pristine (reference) conditions. It is envisioned that sample reaches would be re-visited every five years for the life of the NFHCP. Results will be related to the fraction of Plum Creek's road network that is up to BMP standards over time (which will be related to the expected reduction in sediment delivery through comparison with intensive road sediment delivery analyses).

The second level of investigation involves a limited, but intensive analysis of fine sediment

levels in "demonstration watersheds." One demonstration watershed will be selected in each of three meta-ecoterras where Plum Creek has the largest land ownership. In each watershed, stream guilds will be delineated (See Technical Report #8). Sample sites will be randomly selected within guilds that have moderate-to-high sensitivities to fine sediment delivery in each demonstration watershed. In conjunction with in-stream fine sediment monitoring, a detailed sediment delivery budget will be completed. This budget will estimate: 1) Road sediment delivery (Using the Washington Watershed Analysis approach); 2) In-channel storage (volume) of fine sediment; 3) Bank erosion rates; 4) Landsliding (visible on photographs); 5) Surface erosion from hillslopes; and 6) Near-channel landslides not visible on air photos. This watershed sediment budget will be updated through time and be related to trends in in-stream fine sediment levels. It is envisioned that sample reaches would be re-visited every five years for the life of the NFHCP. Trends in fine sediment levels will be directly compared with estimates of sediment delivery over time. Demonstration watersheds would also be used to develop a relationship between surface measurements of fine sediment and fine sediment levels in the inter-gravel environment (based on McNeil core samples). This would establish a tie between monitoring of surface fines and spawning habitat.

Use of Results: Results will be used to verify the in-stream benefit/response of reducing fine sediment supply over time. Though we are not specifically targeting bull trout spawning reaches for this study, it is expected that the results would be indicative of the trend in the quality of spawning habitat over time. This will be verified in the demonstration watersheds.

The exact in-stream response that would be realized from reducing fine sediment supply is related to numerous factors, including the magnitude of sediment reduction in relation to background erosion rates (i.e. the change in watershed sediment supply) and the volume of sediment in storage as a fraction of the annual watershed sediment yield.

If there is not a significant difference in in-stream fine sediment levels over time among treated and untreated watersheds, this would not lead to a decision that we should abandon BMPs, or that improving road drainage is not a good idea. It may simply be that sediment supply from roads was not high enough above background levels in the first place to significantly elevate in-stream sediment levels. Such a result may indicate that we should not spend significant additional resources to further reduce fine sediment supply. Additionally, due to routing of sediment through streams, the impact of legacy impacts may continue to be manifest in stream conditions well beyond the life of the plan.

Results from this study are expected to have benefits beyond native fish conservation. They can also be used on other forums, such as development of Total Maximum Daily Loads (TMDLs) under the Clean Water Act, and Source Water Protection under the Safe Drinking Water Act.

Cost Estimates: The cost of project monitoring is directly related to the number of sample sites, which has yet to be determined. However, this project is expected to keep a two-person field crew busy for an entire summer every five years. Assuming twelve person-months at a cost of $2,000 per month, the total cost would be $24,000. With additional vehicle and travel costs, the total would increase to about $30,000 per year every five years.

Costs of doing detailed sediment budgets in the three demonstration watersheds would be approximately $20,000 each, and would be incurred in the first five years of the plan.

Timetable: Because the upgrade of old roads will be concentrated early on in the life of the plan (in the first ten years), first year data should be collected as soon as possible after signing of the NFHCP. Thereafter, sites would be revisited on five-year intervals for the life of the plan.

Project Title: **A3.   Implementation Monitoring of Road and Riparian Prescriptions.**

Description: This project will involve collecting information on road construction, road maintenance, and riparian timber harvest activities conducted under the terms of the NFHCP. Annual internal (Company) audits will be conducted to document compliance and improve operational implementation of the plan. The project links to NFHCP Technical Reports 3, 6, and 7, and is associated with road and riparian commitments outlined in the NFHCP.

Purpose & Objectives: This project is designed to gather information for the purposes of documenting compliance with riparian and road commitments in the NFHCP, and for improving implementation. The objective is to ensure 100% compliance of road and riparian prescriptions throughout the planning area.

Hypothesis: N/A

Type of Study: This project is descriptive and is classified as continuous improvement.

Approach: *Methods*—Each year, a sample of road and timber harvest activities will be drawn randomly from within the NFHCP planning area. These sites will be visited by a multi-disciplinary team consisting of individuals from the fields of forestry, hydrology, and biology. This team will evaluate whether the practices implemented at the sites complied with NFHCP commitments. Departures will be documented to identify areas for continuous improvement (e.g., training, clarification, etc.).

Every three to five years, the annual information will be summarized and provided to an independent third-party audit team. This team would review the accumulated information and visit new sites on their own, to report on compliance.

These compliance audits will be complimentary to, and may in some cases be replaced by, other environmental audits conducted by the company (e.g., annual state BMP audits in Montana, Triennial Environmental Principle audits). Representatives from the U.S. Fish and Wildlife Service will be invited to participate in these audits and to review the annual results.

Use of Results: The results of these audits will be used to improve the efficiency and completeness of Best Management Practices for roads and riparian areas developed as part of the NFHCP.

Cost Estimates: An annual budget of about $10,000 will cover costs associated with internal audits.

Timetable: This study is expected to last 30 years from its inception through the term of the Plan. Reports and analysis will follow each measurement period.

This type of study could be initiated as soon as desired after the NFHCP is signed.

Project Title: **B3. Evaluation of the effectiveness of NFHCP riparian management strategies at maintaining maximum water temperatures close to background.**

Description: This study involves collecting continuous summertime water temperature data above and below timber harvests that border perennial streams, both before and after harvesting. It is expected that this study will reveal if maximum water temperatures measurably change due to harvesting, and if so, what the magnitudes of those changes are. Data will also be collected on a variety of stream and riparian attributes that can assist in stratifying the sample sites and explaining any observed changes. This study links to NFHCP Technical Reports #7 and #12, and is associated with all riparian management commitments in the NFHCP.

Purpose & Objectives: The purpose of this study is to examine to what extent NFHCP riparian prescriptions maintain maximum water temperatures close to background temperatures.

Hypothesis: There is no significant difference in the ratio of water temperature upstream of NFHCP riparian harvest areas to water temperatures downstream of harvest areas, before and after timber harvest.

Type of Study: This is study is experimental research and is intended to determine if NFHCP riparian harvest treatments maintain water temperatures close to background (i.e., biologically significant changes are not observed).

Approach: Data will be collected using electronic thermographs. At each site, thermographs will be installed immediately above the riparian area to be harvested, immediately below the riparian harvest area, 500 feet below the harvest area, and 1000 feet below the harvest area. At a minimum, data will be collected during the months of July and August in advance of the treatment.   This will establish the relationship between upstream and downstream temperatures. This relationship could be established by regressing upstream to downstream daily maximum temperatures, or could be a simple ratio of the upstream maximum weekly maximum temperature (MWMT) to the downstream MWMT.

Plum Creek foresters will be queried for all riparian harvests that meet the following criteria:

- **Harvest will take place along at least 1000 feet of a perennial stream on at least one side of the stream.** This will ensure that the stream has had a reasonable distance to equilibrate to the harvest conditions.

- **Harvest will take place after peak water temperatures are measured (September 1st) and will conclude by the end of the following spring (June 1st).** This will ensure that timber harvest is not taking place when thermographs are in the water.

- **No other timber harvest activities will occur upstream of the stream reach to be monitored for the duration of the study where that harvesting could influence the temperature of the monitored reach.** The attempt here is to isolate the treatment for the period of the study.

In addition to temperature data, we will collect information on stream channel and riparian characteristics. Stream channel data would include bankfull and wetted stream width, low flow stream depth, azimuth, aspect, substrate composition, and habitat unit composition. Riparian data would include tree height, diameter, and stocking level information that can be obtained with a riparian timber cruise. Data will also be collected on canopy cover upstream, within, and below the treated reach. Canopy cover would be measured using concave spherical forest densiometers using protocol outlined by Platts et al. (1987).

All thermographs will be calibrated in an ice bath (~0°C) prior to deployment. Thermograph readings will also be periodically compared with field-measurements of water temperature using a laboratory-grade thermometer.

Stream and habitat data collected before and after harvesting will be used to stratify sample sites. This could include stratification based on stream size, stream gradient, riparian treatment, stream guild, treatment length, meta-ecoterra, etc. We expect that once we stratify the data we will only be able to make generalizations about some situations. It could take several years to collect enough data to evaluate effectiveness for some treatment types (e.g., high risk CMZs), stream sizes (e.g., larger streams), or small meta-ecoterra zones or other variables. This could be avoided by performing an analysis of covariance with the data.

Thermograph data taken 500 and 1000 feet below the harvest areas will be used to examine how water temperature changes below the treatment reach. That is, if temperatures increased 1°C due to the treatment, did they cool to background temperatures within 500 feet? 1000 feet? This information will help validate our NFHCP prescriptions for temperature control in non-fish-bearing perennial streams.

We anticipate being able to sample virtually all timber harvests Plum Creek that meet the criteria listed above. If the number of harvests that meet the criteria above is more than can be surveyed, sample sites will be selected at random.

Use of Results: It is possible that this study will reveal statistically significant changes in water temperatures at some locations or in some situations. Where these changes are observed, it must be decided if they are biologically significant. This would logically be a function of: 1) the magnitude of the change; and 2) The temperature range in which the change is observed. For example, a 1°C increase in maximum water temperature (in excess of calibration or measurement error) in a bull trout stream might not be particularly significant if maximum water temperatures were still in the optimal range for juvenile rearing (say below 15°C for the MWMT). However, this 1°C increase in MWMT could well be biologically significant with water temperatures in excess of 15°C. Where biologically-significant changes are observed, a reach- or watershed-specific temperature control plan should be developed to keep the

problem from being worsened.

This study will reveal those specific riparian treatments that consistently result in biologically-significant increases in water temperature. Subsequent studies can be designed to evaluate alternative treatments needed obtain more favorable temperature regimes. The outcome of this subsequent investigation would be specific direction for necessary modification of the NFHCP.

Cost Estimates: Cost of thermographs would be about $100 each. With four thermographs per site, the cost per site would be approximately $400. Assuming we had 30 sample sites in the first year, and another 30 sites in the second year, this would be a total thermograph cost of $24,000. To deploy the thermographs and collect stream/riparian data, we would need approximately 5 months of seasonal time for the three summers of the study. At a cost of $2,000 per month, this would be a total cost of $30,000. Total cost of the project would therefore by approximately $54,000. This does not include costs associated with additional investigations that may be warranted.

Timetable: This study is expected to last 3 years from its inception and could be initiated as soon as desired after the NFHCP was signed.

Project Title: **B4 Use of aquatic ecoclassification for enhanced protection of aquatic resources within the NFHCP project area.**

Description: This project entails the delineation of meta-ecoterra zones across the NFHCP project with subsequent classification of fluvial habitats so as to stratify groups of channel segments exhibiting similar characteristics in terms of physical habitat characteristics, fish species utilization, and relative sensitivity to input processes potentially modified by upland land management activities. It is anticipated that once clusters of channel segments are delineated and described, a GIS-based spatial template of said clusters can be used to: 1) identify areas of varying degrees of biological importance, 2) stratify stream reaches for comparative before-after-control-impact (BACI) investigations, and 3) provide managers with a tool for the modification or prioritization of both riparian and road management activities. This project links to Technical Reports #8, #7, and # 3, and is associated with riparian and road management commitments identified in the NFHCP.

Purpose & Objectives: The objective of this project is to provide a more complete understanding of the distribution and relative sensitivities of fluvial habitats across the planning area in order to enhance our ability to predict the potential of management related cause-and-effect processes to impact fish habitats, resulting in a further reduction of the risk of management actions to native salmonids.

Hypothesis: That the delineation of meta-ecoterra zones with subsequent hierarchical ecoclassification will provide for the stratification and identification of functional groups of channel segments in which habitat features, fish population assemblages, and sensitivities to land management can be predicted with a high level of statistical confidence.

Type of study: This study is conceptually both descriptive and inferential. The project is descriptive in that it will allow for the identification of various stream reaches within the planning area that can be described in terms of habitat characteristics and fish use. The channel typing approach will also provide a basis for stratification in the sampling design of other inferential projects investigating cause-and-effect mechanisms, thus minimizing the potential bias or error associated with the variance of independent physical factors. The project is inferential in that the enhanced ability to identify the various sensitivities of stream reaches can result in the modification of management treatments to improve both aquatic resource protection and management efficiency (commodity production and commitment of fiscal resources).

Approach: Meta-ecoterra zones will be identified throughout the NFHCP project areas. Large scale geologic and climatic variables will be used to differentiate the various zones. The proposed approach in the delineation of meta-ecoterra zones will be to identify a geographic area(s) encompassing the combination of geologic district and geomorphic class (i.e., fluvial lands vs. alpine glaciated lands), defined as a subsection. Once all subsections in the planning area are mapped, a meta-ecoterra zone is considered as those geographic areas, with a subsection, that exhibit similar precipitation and solar radiation regimes. Using this definition, preliminary analysis suggests that 6 to 10 meta-ecoterra zones exist within the planning area.

Once all meta-ecoterra zones are identified, a hierarchical ecoclassification (as described in Technical Reports #8 and #4) will be conducted for each zone to identify and map dominant geomorphic guilds. Guilds are defined as those channel segments within the same landtype and exhibiting similar stream order, valley bottom slope, and channel confinement. Representative segments of all dominant geomorphic guilds will be randomly selected and sampled for an array of geomorphic, physical habitat, and biological variables. Statistical analysis of the data will be conducted and cluster analysis will be used to group geomorphic guilds into super guilds, as described in Technical Report #8.

Representative super guild segments will be assessed for channel sensitivity and fish habitat vulnerability using watershed analysis methodology. Super guild clusters may be modified based on the results of the watershed analysis modules. A final beta-test of the predictive power of the super-guild classification will be conducted via sampling previously un-assessed super guild channel segments and comparing results to samples collected during the initial phase of the analysis. If the super guild classification approach is found to be accurate at predicting fish habitat attributes, fish population use and distribution , and channel segment sensitivity and vulnerability, the hypothesis will be accepted and the array of attributes of super guilds will be extrapolated to all respective super guild segments within the meta-ecoterra zone.

Concurrent to ecoclassification and super guild stratification, assessment, and extrapolation, a mass-wasting analysis will be conducted for the subject meta-ecoterra zone and a hazard zonation map for mass-wasting (landslides, inner gorges) will be prepared, likely linked to landtype classes identified via the ecoclassification.

Plum Creek will be responsible for all data collection, analysis, storage, and retrieval. Access to the data will be limited to agencies and participating scientists.

Use of Results: It is expected that the results of this project will have several applications. Once channels are stratified, assessed, and described, it is expected that the identification of biologically significant areas (such as important spawning areas) will become readily apparent. Additionally, guilding should assist in the identification of areas with a high likelihood of supporting native species assemblages. Conversely, channel types exhibiting severe exotic species infestations can be located for potential suppression/eradication efforts.

It is anticipated that ecoclassification will be useful in the identification of locations where management actions may need to be either modified or prioritized. For example, spatial locations of sediment-sensitive guilds could be used as a tool for the prioritization of road drainage improvement activities. The identification of a specific guild's vulnerability relative to large woody debris could be used to justify the modification of slope-based riparian management prescriptions.

Ecoclassification and guilding will be used to develop a GIS-based planning tool for foresters and managers. The identification and location of channel types with a high probability of lateral migration, for example, will be useful information to foresters in terms of timber sale layout. The mass-wasting hazard map will provide managers with information regarding the specific risks of road construction in certain areas.

Lastly, the results of ecoclassification can be used to identify stream reaches appropriate

for the implementation of causal-comparative studies, thus minimizing natural variation of independent factors that could mask the cause-and-effect process being investigated. Hence, internal validity of the experimental design would be maximized. Additionally, external validity of said experiments could be enhanced by using guild types to identify areas appropriate for the implementation of management shifts induced by said cause-comparative studies.

Cost Estimates: As stated above, it is estimated that the project area contains 6 to 10 meta-ecoterra zones. For each meta-ecoterra zone it is estimated that the cost of conducting a hierarchical ecoclassification would be $25,000, data collection would equal $45,000, channel condition and fish habitat evaluation would cost approximately $17,000, and mapping and statistical analyses would cost $10,000. Hence the cost for project application would be approximately $97,000 per meta-ecoterra zone with a total project cost between $582,000 and $970,000 (6 to 10 zones, respectively).

Timetable: This project is expected to last 6 to 10 years, assuming that one meta-ecoterra zone analysis could be conducted per year.

Project Title: B5. Effectiveness of Plum Creek's Grazing BMPs

Description: This project involves collecting data on riparian condition and fish habitat over time and comparing these trends among various grazing management strategies. It links to Plum Creek's Grazing Best Management Practices (BMPs) and a white paper titled "Livestock Grazing on Plum Creek Timber Company Lands in the NFHCP Area." It relates to all range management commitments detailed in the NFHCP.

**Purpose &
Objectives:** To obtain information on the overall trend in riparian condition and fish habitat in the NFHCP area, and relate this trend to implementation of Plum Creek's Grazing BMPs and other more restrictive management approaches.

Hypothesis: That riparian condition, fish habitat, and fish biomass will improve/increase over time in response to implementing Plum Creek's Grazing BMPs.

Type of Study: This study is experimental research since we seek to establish a cause-and-effect linkage between implementation of various treatments (grazing management strategies) and riparian condition and fish habitat. It is classified as experimental management.

Approach: Fish use in streams in the NFHCP area is concentrated in stream gradients less than 4%. These same stream reaches tend to be most sensitive to grazing disturbance. Using Plum Creek's Geographic Information System (GIS), we will identify all perennial stream segments in grazing allotments that have a gradient less than 4%. Then, through conversations with Plum Creek foresters, scientists, and range managers, segments that are known to be moderately-to-severely impacted by cattle grazing will be identified. Another approach that could be used is the University of Montana's Riparian Health Assessment. Once identified, approximately 20 of these stream segments will be randomly selected for long-term monitoring.

Each of the 20 stream reaches selected will be assigned one of four treatment types (5 reaches each):

 Season-long grazing without BMPs
- Season-long grazing implementing Plum Creek's Grazing BMPs (BMP System 1)
- Short-duration or "controlled" grazing (e.g., riparian pasture) implementing Plum Creek's Grazing BMPs (BMP System 2)
- No grazing (exclosed to cattle grazing via fencing)

Stream reaches will be sampled every five years. Data to be collected include stream (fish habitat) characteristics (e.g., pool depth, % surface fine sediment, channel width, % over-hanging banks, % cover, etc.), riparian characteristics (e.g., vegetation composition, vegetation type, etc.), and the fish community (e.g., species, size class, abundance).

The exact study design will be developed in cooperation with the University of Montana Riparian Wetland Research Program.

Use of Results: Data will be used to examine effects among the four treatment types. This feedback will be used to adjust management strategies on the rest of Plum Creek's grazing leases as soon as 5-10 years after inception of the project. Data will also be used to measure the overall benefit of implementing Plum Creek's Grazing BMPs.

Cost Estimates: It is expected that a crew of two could collect and compile the necessary data in two months. Assuming $2,000 per month per seasonal, this would be $8,000. Including vehicle and travel, it is expected that the total cost would be about $10,000 each time data were collected. Initial start-up costs would be higher (maybe as high as $30,000)

Timetable: First year data would be collected within two years after implementation of the NFHCP. It is envisioned that these data would be collected every five years thereafter for 20 years.

Project Title: **B6 Effectiveness of riparian/stream enhancement along key migratory rivers**

Description: The project area contains 111 miles of key migratory rivers (or corridors) on Plum Creek land which are important for migration and foraging of bull trout and other native salmonids, and are key connection routes for bull trout to maintain a migratory life form. This project will involve collecting data on riparian condition and fish habitat along key migratory rivers where riparian and/or stream enhancement has been undertaken as part of the NFHCP, and comparing these data over time with conditions in untreated areas. This project relates to NFHCP commitments regarding Legacy and Restoration of historic land use activities.

Purpose & Objectives: To obtain data on the trend in riparian/stream condition and fish habitat and relate this trend to enhancement activities.

Hypothesis: That riparian condition and fish habitat will improve over time in response to implementing enhancement projects along key migratory rivers and that improvement will be more rapid than untreated control reaches.

Type of Study: This study is experimental research since we with to obtain a cause-and-effect linkage between implementation of various enhancement projects and riparian condition and fish habitat. It is classified as experimental management.

Approach: Riparian and/or stream enhancement will be undertaken on select portions of key migratory rivers which have been identified as most severely impacted due to legacy forestry activities, cattle grazing, or agriculture. This study will utilize a B.A.C.I. design where riparian and habitat data are taken on randomly selected treatment (impact) and control stream reaches on severely-impacted key migratory rivers.

It is envisioned that there would be three control reaches and three treatment reaches. In each reach, data will be taken on in stream characteristics (e.g., pool depth, % fine sediment, channel width, % over-hanging banks, % cover, etc.), riparian characteristics (e.g., vegetation composition, vegetation type, etc.), and the fish community (species and size class distribution of fish). This information could be supplemented with aerial photographic monitoring.

Use of Results: Results will be used to quantify the costs and benefits of undertaking riparian/stream enhancement along key migratory rivers in the planning area.

Cost Estimates: It is envisioned that data collection and compilation would taken approximately three days per sample site. This would be a total of 18 days, or one month of seasonal time. Assuming $2,000 per month for seasonal costs, this would be $4,000. Including vehicle and travel, it is expected that the total cost would be about $5,000 each time data were collected.

Timetable: First year data would be collected within four years after implementation of the HCP. It is envisioned that these data would be collected every five years thereafter for 25 years.

Project Title: **A6 Bull trout redd count monitoring.**

Description: This study consists of monitoring bull trout redd counts in specific index reaches as an indicator of bull trout population trends. This study is not linked to any Technical Reports nor any commitments identified in the NFHCP. Rather, long term monitoring is intended to be generally reflective of bull trout conservation efforts implemented by Plum Creek and other land and fishery managers within the range of specific metapopulations.

Purpose & Objectives: Study objectives are to document bull trout population trends at both the metapopulation scale and subpopulation scale for specific drainages within the NFHCP planning area.

Hypothesis: That population trends at the metapopulation scale will be stable to improving and that trends will be consistent across subpopulations.

Type of study: This study can be considered as descriptive since it entails monitoring of population trends and is not intended to document any specific cause-and-effect relationships. This project can be classed as continuous improvement monitoring.

Approach: Plum Creek has been cooperating with the Montana Department of Fish, Wildlife, and Parks (MFWP) and the USDA Forest Service in the monitoring of bull trout redd counts in the Blackfoot and Swan River drainages. In the Swan River drainage, Plum Creek has monitored redd counts in Jim Creek, Piper Creek and Cold Creek, while MFWP has been monitoring redds in six other streams in the drainage, the period of record is 16 years. In the Blackfoot River drainage, Plum Creek has monitored redd counts in Belmont Creek and Gold Creek while MFWP and the USDA Forest Service have monitored redd counts in twelve six other streams in the drainage, with the period of record ranging from 1 to 11 years, depending on the specific stream. In both river drainages, redd counts have shown a general increasing trend, suggesting positive population growth for the respective metapopulations. Plum Creek and the other cooperators plan to continue annual redd counts. Considering past, present, and future conservation efforts, it is anticipated that bull trout metapopulations will continue to exhibit increasing trends.

Use of Results: If redd count monitoring indicates that all tributary subpopulations exhibit generally stable to increasing trends and if subpopulations exhibit a generally consistent response, it can be assumed that ongoing conservation efforts are successful.

If all subpopulations tend to exhibit a decreasing trend, this suggests that impacts are occurring throughout the metapopulation and are likely related to either 1) large scale climatic effects affecting habitat in all tributaries and/or 2) impacts to the metapopulation are focused in adult/subadult rearing and or migration habitats. In this instance, Plum Creek would likely assist other management entities in identification and rectification of the impact scenario, if within the company's managerial and legal authority.

If most subpopulations within a drainage exhibit a stable to increasing trend and one or a few subpopulations exhibit a decreasing trend, this suggests that impacts are occurring at a localized scale, such as within-tributary habitat, fishing, or competition/predation effects are occurring. Under this scenario, Plum Creek would likely conduct more intensive, causal-comparative studies in the impacted tributaries in question in order to identify, isolate, and rectify the problem.

Cost Estimates: At the current level of monitoring, costs are approximately $2000 per year.

Timetable: Monitoring of redds is anticipated to persist throughout the NFHCP period, contingent upon collaborative efforts with Montana Dept. Fish Wildlife and Parks

Project Title: **C1 Gold Creek experimental brook trout suppression project.**

Description: This project is intended to evaluate the efficacy of brook trout population suppression via multiple-pass electrofishing removal. Effectiveness of suppression efforts will be evaluated through monitoring both the response of native species populations as well as documenting the extent, locales, and timing of brook trout re-invasion. This study links to Technical Reports #1 and #8, and is associated with legacy commitments to evaluate exotic species suppression as identified in the NFHCP.

Purpose & Objectives: Study objectives are to evaluate the potential of exotic species suppression efforts in terms of the applicability to conservation and restoration of populations of native salmonids.

Hypothesis: The null treatment hypothesis is that the density of bull trout (and westslope cutthroat) will not significantly differ before and after suppression treatment and that population response will be modulated by channel type (defined by stream size, gradient, and confinement).

$$m_1 = m_2$$ where d1 = density of bull trout before treatment and d2 = density of bull trout after treatment

Type of study: This study can be considered as inferential because of the experimental removal of brook trout and the assessment of responses by native salmonid assemblages. Methods and results derived through project implementation will likely be applied to other areas, if suppression efforts are found to be successful. That is, if findings indicate that suppression of exotics can be accomplished and if populations of native stocks demonstrate a positive response, it is conceivable that the methodology can be successfully applied in other watersheds exhibiting similar characteristics. Hence, the development of this technique can be classed as basic research.

Approach: Gold Creek, a Tier 1 watershed in the Blackfoot River drainage, will be the study area for this project. Gold Creek provides spawning and rearing habitat for a subpopulation of fluvial bull trout from the Blackfoot River metapopulation. A high gradient confined canyon reach exists within approximately 2.5 miles of the stream mouth and is presumed to be an effective barrier to brook trout immigration from the Blackfoot River, but not to bull trout. Upstream of the canyon reach, Gold Creek supports westslope cutthroat, bull trout, and high densities of brook trout (historically stocked in low gradient reaches above the canyon).

All stream reaches in the Gold Creek watershed above the canyon will be geomorphically stratified based on order, gradient, and confinement. Starting at the canyon reach and working upstream, 300-meter stream reaches will be successively cordoned with block nets. For each 300-meter reach, fish populations will be estimated (by species and size class) via day-snorkeling. Following snorkel estimates, populations will be estimated via multi-pass electrofishing. During electrofishing surveys, all bull trout and cutthroat will be returned live to the stream while all brook trout will be euthanatised and disposed of above the flood-prone-width of the channel. This work will proceed upstream throughout the watershed until several successive reaches, devoid of brook trout, are encountered (presumably the upstream limit of brook trout distribution as dictated by increasing

gradient). Population data will be stratified by geomorphic channel type and correlations will be developed between snorkel and electrofishing population estimates.

Over successive years, population estimates will be obtained by subsampling geomorphic reach types via day snorkeling. Previously developed correlations will be used to estimate total population size by reach type. Hence, population response to suppression treatment can be evaluated for each species, stratified by channel type. It is expected that population responses, of both native and exotic stocks, will vary among the different geomorphic types.

This project will be conducted with the cooperation of the Montana Department of Fish, Wildlife, and Parks (MFWP). Plum Creek will be responsible for data collection and analysis. All data will be shared with MFWP and other parties may be provided limited access to the data.

Use of Results: Data will be evaluated to determine if native species exhibit a positive response, in terms of population density, age structure, and/or expanded distribution, to the initial suppression efforts. Geomorphic reach types will be ranked based on response. Additionally, brook trout population recovery will be evaluated and ranked by geomorphic reach type. Depending upon results, follow-up suppression efforts may be implemented if deemed necessary and likely to benefit native stocks.

If monitoring results suggest that native stocks exhibit a statistically significant positive response to suppression treatments, study findings may be utilized to identify other locales/drainages within the NFHCP planning area where additional suppression efforts may benefit native stocks. That is, suppression efforts in certain channel types may result in a positive response from native stocks where other channel types exhibit no response or rapid recovery of exotics. In the interest of cost versus benefit, expanded suppression efforts may be focused on channel types where recovery of native stocks can be accomplish with minimum cost and/or effort.

Cost Estimates: Initial, first year, data collection and suppression efforts are estimated to cost approximately $30,000, considering travel, materials, and personnel. Follow-up annual monitoring and site-specific suppression is estimated to cost $5,000 per year. Total project cost is estimated to equal $55,000.

Timetable: Phase 1 of the study will commence in the summer of 1999 with initial treatments and density estimates for a period of 2 years. Phase 2 will involve the operational implementation of the technique to other watersheds after evaluation of biological and economic efficacy.

Project Title: **B2 Evaluation of the effectiveness of NFHCP riparian management strategies at maintaining natural levels of in-channel LWD** .

Description: This study will involve measuring trends in LWD loads through time. This study links to NFHCP Technical Reports #7 and #8, and is associated with all riparian management commitments outlined in the NFHCP.

Purpose &

Objectives: The purpose of these studies is to examine to what extent our riparian management commitments developed as part of the NFHCP maintain LWD loads. See sub-project objectives in the approach section below.

Hypothesis: There is no significant difference in LWD loads through time where riparian prescriptions from the NFHCP have been implemented.

Type of Study: This is a mix of inferential and descriptive studies/monitoring.

Approach: Three levels of investigation are proposed:

(1)   Extensive and prolonged

This is an inferential study that involves monumenting and measuring an adequate number (*5-10*) of stream reaches in the project area where harvest will occur according to one of the prescriptions in the HCP. The objective is to determine the overall effectiveness of riparian prescriptions for maintaining LWD loads. The hypothesis to be tested is that, on average, over the entire project area, the various treatments will have no effect on in-channel LWD loads. Reaches with no harvest will be included as "controls". At each site, data will be collected on a variety of stream and riparian attributes that can assist in stratifying the sample sites and explaining any observed changes.

(2)   Intensive and prolonged

This involves a suite of inferential studies where stream reaches and their adjacent riparian forests in a select few watersheds within the project area are measured repeatedly throughout the plan term. In these "demonstration watersheds", the effect of timber harvest on the riparian cause-effect pathway will be the focus for monitoring. An array of treatments (prescriptions from Term Sheet) will be applied to each of the four harvestable stand types, plus a no harvest "control" (*where possible, number of controls should equal replicates*) for each of four channel types.   The effectiveness of the riparian strategy for both fish-bearing and non fish-bearing streams can be addressed through this level of investigation, in concert with the extensive/prolonged effort. In the riparian forest, changes in growth and yield (incl. mortality) will be tracked. In the adjacent stream channel, the following responses will be measured:

Channel Morphology
Sediment storage, channel pattern, channel dimensions
LWD flux *(i.e., the wood budget)*

-*Inputs* (i.e., LWD recruitment [*note: it may be important to separate input from upstream locations and adjacent riparian stands*]
-*Storage* (mapped, measured, and marked LWD)
-*Outputs* (calculated loss through time)
Fish Habitat
Pools, fine sediment in spawning gravels, complexity (eg., undercut banks)
Temperature
Fish Population Response
Population numbers, age and size classes, relative abundance of species

(3)   Intensive and immediate
This is descriptive research to validate assumptions used in estimating LWD loads through time. Topics include:

- Recruitment mechanisms by channel gradient class (e.g., bank erosion rates)
- Angle of tree fall by slope class and distance from the stream
- Source distances
- Relationship between stand type and in-channel LWD loads in unmanaged streams
- Response of different channel types to LWD loads.

These three levels of investigation are needed for the LWD pathway because of the anticipated time lag between treatment and stream channel/fish habitat response. In other words, if we wait to evaluate whether the prescriptions are working, all riparian areas will have been "treated" and we will have little to adaptively manage until the trees grow back. Models (FVS and RAIS) address this problem by enabling reasonable projections of future outcomes. Model improvement in and of itself is not an objective, but validation of the assumptions in the model is important and can drive policy changes.

Use of Results: Results of the "intensive/immediate" studies are expected to be useful for adjusting our riparian prescriptions in the near term, where needed. For example, if several assumptions that are presumed to be conservative instead turn out to be liberal (i.e., less LWD delivered to the channel through time), such that LWD loads were on the whole not expected to be maintained, one or more prescriptions could be changed.

Results of the "intensive/prolonged" studies are expected to yield information on cumulative effectiveness at the watershed scale, on resource trends, and on a variety of other useful topics for improved management.

The "extensive/prolonged" studies will provide information for adaptive management that can be used in the decision system proposed for the stream temperature effectiveness monitoring.

Cost Estimates: *Not yet determined.* Approximately $50,000 per demonstration watershed will be needed to establish monitoring sites. This includes site selection, initial surveys and reporting. Frequency of repeat

measurements will vary by topic and objective (e.g., once every 5-10 years for growth and yield questions, vs. twice total for specific tasks in the "intensive and immediate" category.

Timetable: The prolonged elements of this study are expected to last 30 years from the project inception and could be initiated as soon as desired after the NFHCP is signed. The immediate study topics could also begin as soon as the 1999 field season, and could be largely completed within 1-3 years.

Project Title: **C3..Validation of the Forest Vegetation Simulator (FVS) Riparian Forest Stand Development.**

Description: This study will involve collecting riparian stand data from riparian forests that border perennial streams. Tree mortality is an important element of the LWD recruitment process that is not fully understood. This study validates the riparian forest stand projections derived from the Forest Vegetation Simulator (FVS) by analysis of basic assumptions of forest growth and development. This study links to NFHCP Technical Reports #7, and is associated with riparian commitments outlined in the NFHCP.

Purpose & Objectives: The purpose of this study is to examine the effect of NFHCP riparian management treatments on forest growth and development. The objective is to establish confidence in the predictions derived from the FVS model and to provide the information needed to adjust riparian management strategies where goals (e.g. stand development targets and resultant LWD loads) are not being achieved.

This study validates that the output from the Forest Vegetation Simulator (FVS) is properly controlled and offers realistic input to the Riparian-Aquatic Interaction Simulator (RAIS) model (Technical report #7 and Adaptive Management Project B-2). RAIS makes long-term predictions about the LWD dynamics of a variety of forest types in the NFHCP area.

This is not a full calibration of the FVS model, which is a far more intensive effort that would require re-fitting of the growth equations. However, the data from this project could be used in a larger, multi-organizational initiative that would calibrate the FVS model for riparian forest types.

Hypothesis: There is no significant difference in the growth response predicted in the FVS projections (i.e., projected) and empirically derived growth response (i.e.,. actual).
$$\text{Ho: } m \text{ Projected} = m \text{ Actual}$$

Sub-components of forest stand dynamics can be explored with additional hypotheses, such as:

        Ho: Mortality projections are not different than actual conditions

Type of Study: The study will be descriptive. It provides a look at the riparian forest development process and the resulting stand structures. It is classified as basic research and combines elements of both comparative and BACI study designs.

Approach: *Methods*—Measurements will be taken from riparian forests treated with an array of prescriptions that range from standard rules to no harvest within a distance equal to the height of a site potential tree (i.e., 100 ft).. Permanent plots will be established in each of three demonstration watersheds over the course of seven (east of the Cascade Mtn. Crest) or five (west of the Crest) years. These plots will be periodically re-measured for 30 years to assess performance of the FVS model

Treatments—A variety of cutting treatments are proposed for fish bearing and non-fish

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bearing waters within the agreement area (Tech Report #7). Riparian buffers with variable widths and tree densities will be tested.

Variables (e.g., Parameter design)—Volume by species (from height and diameter measurements) will be calculated for reference stands. Height will be measured to the nearest foot (+/- 1.0 feet) and will be a sub-sample of the plots at an intensity of no less that 20%. Diameter (e.g. at breast height, DBH) is measured 4.5 feet from the average ground level and recorded to the nearest tenth inch (+/- 0.1 inches). The position relative to the stream will be used to assess the potential for providing ecological (e.g. fish habitat) function. These parameters are chosen to be sensitive to changes in stand characteristics that influence the model predictions.

Data will be collected from permanent sample plots (minimum of 3) established in the stands included in the study. Data will be collected the late summer before (T_0) and after the treatment (e.g. T_1, T_3, T_5, T_{10}, T_{15}, T_{20}, and T_{30}). This will establish the relationship between treatment and stand development. Changes in volume growth, height, and diameter will be measured according to standardized regional protocols. Growth previous to the treatments can be calculated by a sample of the radial increment in diameter growth aver the last 10 years, which is done by either an increment borer or ring counts from stumps following treatment

In addition to growth data, we will collect information on riparian characteristics. (e.g. azimuths, aspect, canopy cover within the treated reach, substrate composition, habitat type, understory composition, snags, tree mortality and tree fall rates).

Analysis— Projected stand data and actual stand data (both reference and treatment) can be compared using standard parametric statistical tests (e.g. t-test of stand parameter means). This is a simple but effective test of the model reliability with summary data analysis to assess system performance (e.g., target acquisition). It is possible to set up formal calibration of FVS for a limited set of silvicultural trials (limited primarily because of cost and risk) but this must be undertaken as a separate project. Ideally, such a project would be conducted as part of a larger regional effort.

Additionally, multivariate analysis can be used to begin to describe factors that may be controlling the LWD recruitment process (e.g., eigen analysis) and will require a cross link to the data collected in other Adaptive Management Projects. This is an exploratory data analysis technique.

Use of Results: Any assumptions used in FVS modeling that are found to be critically in error (i.e., such that they significantly alter the outcomes from the RAIS LWD recruitment model) will trigger a re-evaluation and possible adjustment of the NFHCP riparian prescriptions. In addition, the knowledge gained will allow better predictive capability related to the implications of riparian management. Ultimately, this study will contribute to the demonstration of the effectiveness of the riparian strategy to actively manage riparian forests to provide sufficient ecological function.

Cost Estimates: An initial budget of about $135,000 will provide plots in the major demonstration areas.

Re-measurement cycles (i.e., at five- to seven- year intervals) will require about $85,000 for data collection, study site maintenance and data summary.

Cost of the plot establishment, measurement, and analysis depends on the actual size of the study (number of treatments), labor cost, plot size, and degree of reporting required. As an estimate for a working budget, plots are $1500.00 each (design, layout, measurement, and analysis). Initial design includes the following for each demonstration watershed: two stand types (e.g. 2 managed stands, T9 or T15; H9 or H15), five treatments (standard rules, ¼ harvest within 50 ft, no harvest within 50, 75, and 100 ft), and 3 plots per treatment. Cost for this design (i.e., 3 watersheds X 2 stands X 5 treatments X 3 plots = 90 plots) would be approximately $135,000.00 for the start up.

Establishment and initial measurements require approximately 3-5 months of late summers crew time. Data entry will be simultaneous with data acquisition, either by the crew or additional staff. Annual analysis will be minimal initially but will culminate with full reporting and perhaps publication of the results and discussion.

Total cost of the project, assuming a sufficiently robust experimental design, would be approximately $220,000 but could increase substantially if the sites were replicated or the scope was expanded.

Timetable: This study is expected to last 30 years from its inception through the term of the Plan. Initial plot establishment and pre-treatment measurements would be followed by post-harvest re-measurements at year 1, year 3, year 5, and at subsequent five-year intervals (10,15,20,30). Reports and analysis will follow each measurement period.

This type of study could be initiated as soon as desired after the NFHCP was signed.

Project Title: **C2 Evaluation of the effectiveness of NFHCP riparian management strategies to accelerate the growth from stagnant and young, over-stocked stands**.

Description: This study will involve collecting riparian stand data from partial timber harvests that border perennial streams. This study demonstrates the impact on stand level growth due to harvesting based on several different treatments. Data will be collected on riparian attributes that help explain any the riparian stand dynamics. This study links to NFHCP Technical Reports #7 and #12, and is associated with all riparian management commitments outlined in the NFHCP.

Purpose & Objectives: The purpose of this study is to examine to what extent our riparian management commitments developed as part of the NFHCP can accelerate the growth from stagnant and young, over-stocked stands. The benefit to fish is the accelerated development of critical riparian functions associated with stream surface shading and LWD recruitment.

Hypothesis: There is no significant difference in the growth response following partial timber harvesting (e.g., Treated) and no management (e.g., No Treatment) adjacent to perennial streams.

Ho: m Treated = m Non-treated

Type of Study: This is an inferential study and is intended to determine of NFHCP prescriptions can effect the growth of stagnant and young, over-stocked riparian stands. This is a project to investigate the feasibility of a potential tool to accelerate the development of conditions more favorable for native salmonids. This is no specific NFHCP commitment linked to this project. Therefore, it is classified as basic research.

Approach: Data will be collected from permanent sample plots established in the stands included in the study. Data will be collected the late summer before and after the treatment. This will establish the relationship between treatment and stand development. Typically, height and diameter (taken at a specified point on the tree bole, e.g., breast height) are used to compute volume. Changes in volume growth, height, and diameter will be measured following regional standards. Growth previous to the treatments can be calculated by a sample of the radial increment in diameter growth aver the last 10 years, which is done by either an increment borer or ring counts from stumps following treatment

In addition to growth data, we will collect information on riparian characteristics. (e.g., azimuths, aspect, canopy cover within the treated reach, substrate composition, habitat type, understory composition, and snags and tree mortality). Riparian data will also be collected. A parallel study of stream temperature will be assessing the use of concave spherical forest densiometers using protocol such as Platts et al. (1987) versus the use of fish-eye camera lenses to measure canopy cover.

Timber harvests on Plum Creek land would be chosen based on specific stand structure criteria (e.g., age, species, and elevation).

Use of Results: This study will demonstrate effectiveness of the riparian strategy to actively manage riparian forests that are currently not providing sufficient function. The goal is to accelerate the development of large conifer trees that will eventually provide LWD to the channel, stream surface shade (thereby regulating water temperatures), and perhaps a surplus of functional trees (offering landowners a financial incentive to accelerate riparian recovery). As with many risky and unproven conservation strategies it is necessary to define an acceptable change to biological thresholds.

As a contingency, if we find biologically significant increases in the riparian forest growth, no action would be necessary, signaling that projections for the time to develop functional riparian forests were conservative—thinning, in fact, speeds the stand development of critical riparian function. On balance, if the projections were higher than actually realized—liberal in this instance—then some adaptation of the management may be required that would stabilize adverse impacts.

Cost Estimates: Cost of the plot establishment, measurement, and analysis depends on the actual size of the study (number of treatments), labor cost, plot size, and degree of reporting required. As an estimate for a working budget, plots are $1000.00 each. With 12 plots per site, the cost per site (a minimal design of a 2 X 2 ANOVA replicated 3 times) would be approximately $12,000.00.

Establishment and initial measurements requires approximately 3-5 months of late summers crew time. Data entry will be simultaneous with data acquisition, either by the crew or additional staff. Annual analysis will be minimal initially but will culminate with full reporting and perhaps publication of the results and discussion.

Total cost of the project, assuming a sufficiently robust experimental design, would be approximately $50,000-$100,000 depending on the scope of the study.

Timetable: This study is expected to last 30 years from its inception through the term of the Plan. Initial plot establishment and pre-treatment measurements would be followed by post-harvest re-measurements at year 1, year 3, year 5, and at subsequent five-year intervals (10,15,20,25,30). Reports and analysis will follow each measurement period.

This type of study could be initiated as soon as desired after the NFHCP was signed. It is estimated that 2 years would be required for initiation with subsequent measurements every 5 years.